C-139 BASIN VEGETABLE PRODUCTION DEMONSTRATION PROJECT

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Deliverable 1

SFWMD Contract OT051165
Deliverable 5.2

Final Report
(Spring 2006 to Fall 2011)

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This report is dedicated to Dr. Kent Cushman, Vegetable Specialist and first project leader for this demonstration project. His untimely passing during this project was a loss to all participants in south Florida vegetable production.

Information contained in this report has not been subjected to scientific peer review, nor has it yet been incorporated into IFAS recommendations.

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Executive Summary

The C-139 Basin Vegetable Production Demonstration Project took place between 2005 and 2011 to optimize nutrient management practices to reduce phosphorus (P) losses in farm runoff. This project is an element of the water quality initiatives to maintain P discharges in C-139 Basin runoff at historic levels as required by the Everglades Forever Act (Sections 373.4592(4)(f)5 and 6, Florida Statutes) and Rule 40E-63, Florida Administrative Code. Review of basin water quality data and implementation practices suggest that optimization of nutrient management practices is an area of opportunity.

The first three-year phase of this project (Winter 2006 to Spring 2008 growing seasons) focused on demonstrating soil test-based P fertilization rate recommendations, and extension services. The project took place in five farms on green beans, tomatoes, eggplant, peppers and corn. Three different P application rates were applied in sets of three replicate plots and the effects on soil P, biomass, leaf P and yield were evaluated. The application rates ranged from the University of Florida – Institute of Food and Agricultural Sciences (UF-IFAS) standard recommendation based on the Mehlich 1 Test (generally zero application) to the grower's application rate, and included a middle point application of 50% of the grower's application rate.

The second three year phase of the demonstration (Fall 2008 to Spring 2011) increased the number of replicate plots from three to four, demonstrated P application rates assuming low P levels, added evaluation of soil pH moderation using sulfur, slow release (coated) fertilizers, split application via fertigation and foliar application, water quality monitoring, and a comparison of sequential analysis with multiple soil extractants to determine which better estimated plant available soil P under the high pH and Ca conditions prevalent in C-139 Basin vegetable farms.

Freezing temperatures during the life of the project affected six demonstration sites and two demonstration sites had questionable data reducing the number of representative demonstrations with suitable conditions for evaluation from 37 to 29. A description of the demonstrations, crops, weather effects, water quality monitoring and treatments per site is presented in Table ES1. General findings are presented for tomatoes (13) and green beans (12) next. Findings for the other crops (4) are not discussed due to the limited sample. For all demonstrations, soil P at prior to planting was at or above high levels based on the Mehlich 1 extractant (31 mg kg^{-1}).

Effect of P Fertilization Rates

- Results from thirteen tomato demonstrations were available for analysis. Yields statistically increased with P application rates only for half of the demonstrations. Yields generally plateau at rates lower than the grower typical rates or the rate assuming low soil P (approximately 120 lbs/acre). On average, the optimum total relative yield was observed between 60 and 90 pounds of P_2O_5 per acre. Figure ES1 illustrates the relative total yields of tomatoes for all demonstrations not substantially affected by weather. For the demonstrations with statistically significant datasets (those not labeled as "NS" in the legend), a correlation trend was developed.

- Results from twelve green bean demonstrations were available for analysis. Yields statistically increased with P application rates only for one fourth of the demonstrations. In those cases highest yields were observed with rates around the grower typical rate or the rate assuming low soil P (approximately 50 lbs/acre). Figure ES2 illustrates the relative total yield of green beans for all demonstrations at the varied rates, and includes a trend line based on the statistically significant datasets excluding those with questionable data.

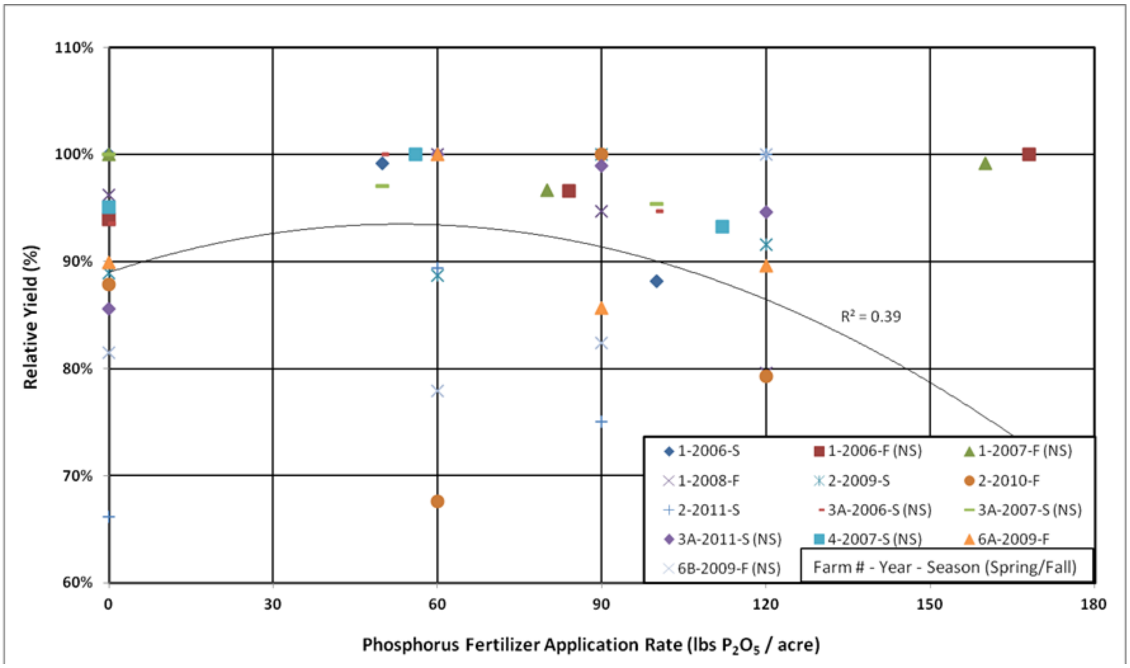

Figure ES 1: Percent of Maximum Yield for Tomato.

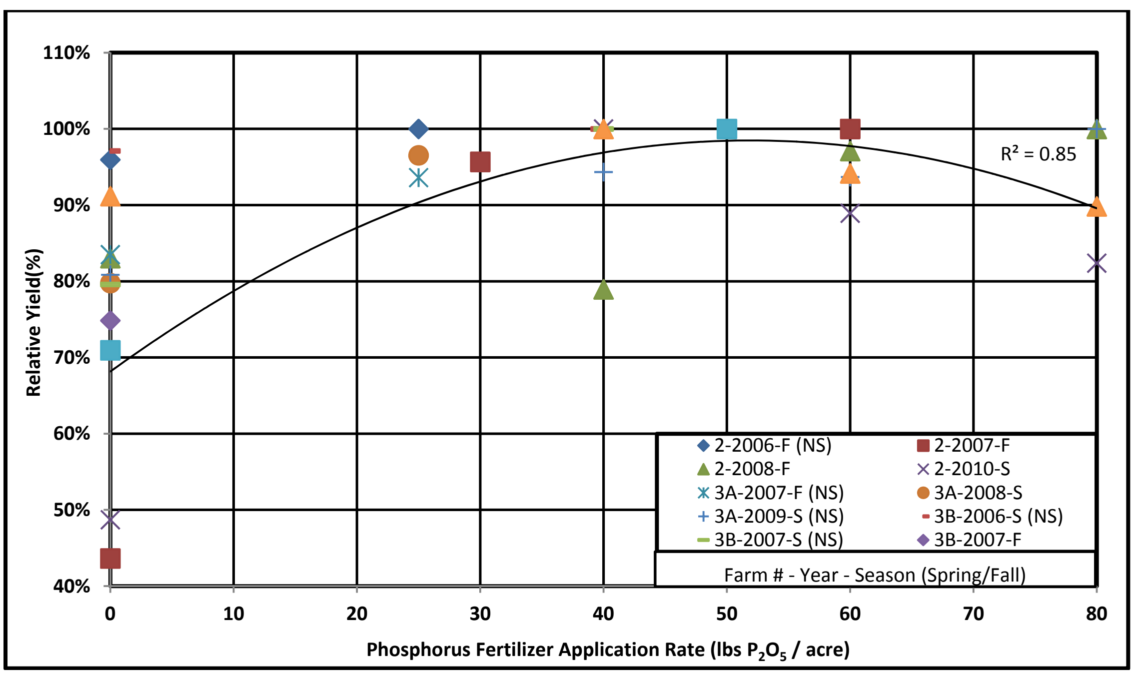

Figure ES 2: Percent of Maximum Yield for Green Beans

- Leaf, stem or fruit biomass did not consistently increase with P application rates. Contrasting results for tomatoes and green beans were found, while a statistically significant effect was observed for tomatoes during the second phase of the project with highest biomass between 60 and 90 pounds of P_2O_5 per acre on average (Figure ES3), statistically significant effects for green beans were only observed during the first phase of the project (Figure ES4).

- Total P tissue data were available for three tomato demonstrations and indicated comparable accumulation levels at rates ranging from 60 to 120 P_2O_5 pounds per acre. Leaf P concentrations met the sufficiency levels (0.2 to 0.4 mg kg^{-1}) at all application rates.

- For tomatoes, statistically highest soil P levels at harvest were observed at application levels of 50 P_2O_5 pounds per acre and highest. For green beans, which use lower application rates, no consistent results were obtained.

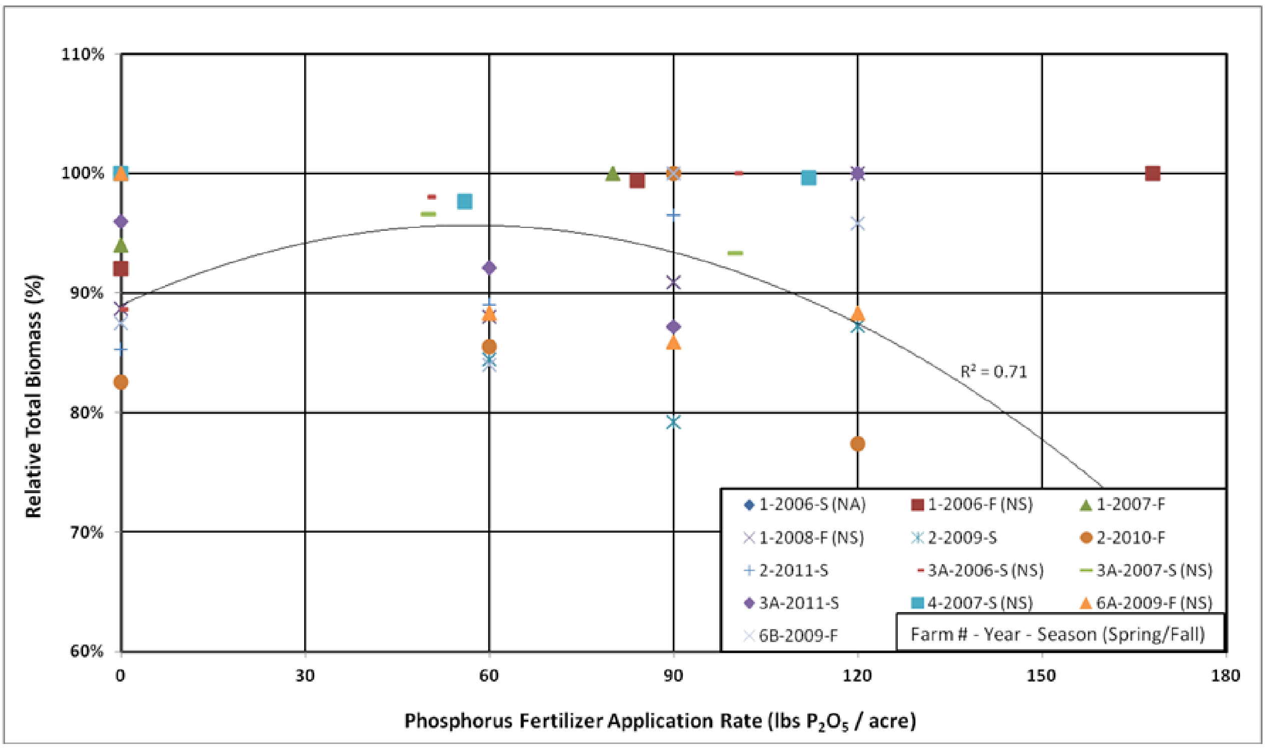

Figure ES 3: Percent of Maximum Biomass for Tomato.

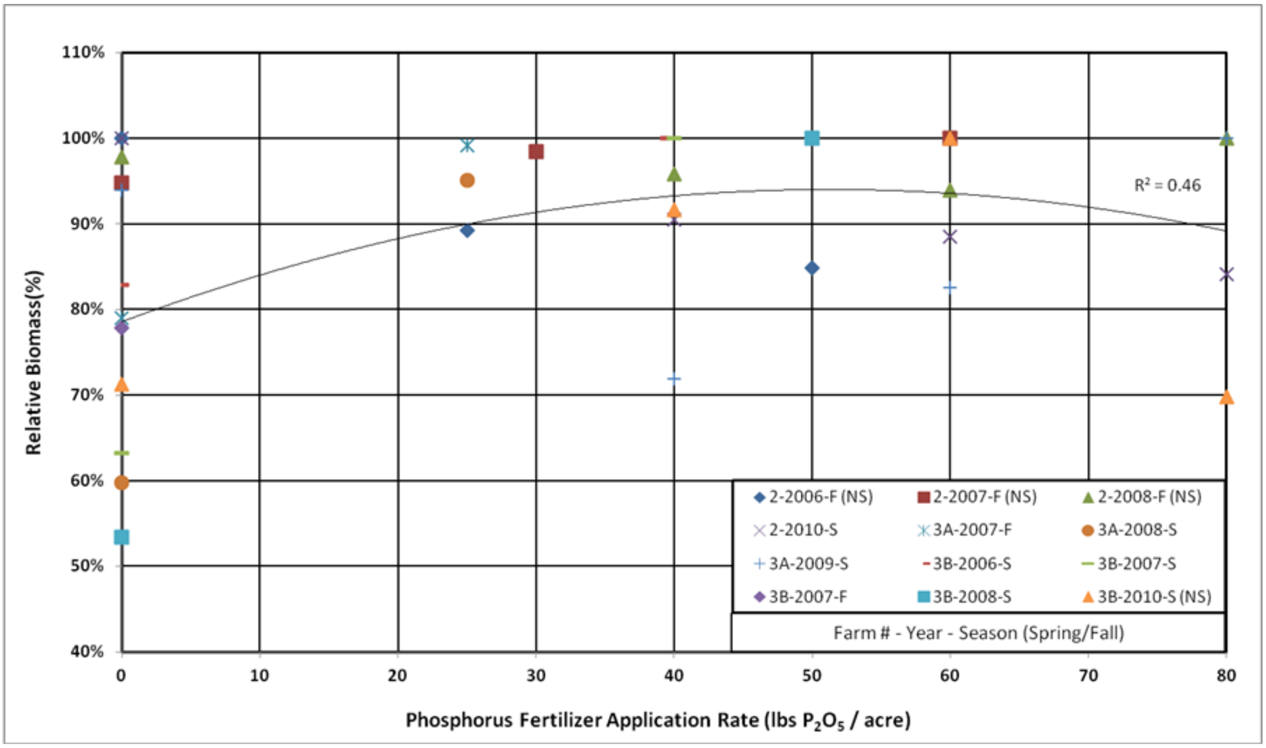

Figure ES 4: Percent of Maximum Biomass for Green Beans

Effect of sulfur coated and polymer coated fertilizers

- Results from only three tomato demonstrations were available for analysis. For the farm with two demonstrations, statistically similar highest yields and total biomass were obtained with polymer coated fertilizer at the zero P_2O_5 rate in contrast with rates of 90 or 120 P_2O_5 pounds per acre rates when uncoated fertilizers were used. However, for the farm with one demonstration, the statistically highest total yield was obtained with uncoated fertilizer and the statistically highest total biomass was also obtained with lower rates of uncoated fertilizer. Similar levels of P tissue accumulation at harvest were observed for combinations of coating and P rate. Results on the effect of coating fertilizer on soil P varied from demonstration to demonstration. There were no statistical significant differences in water quality data at different application rates. Regarding coating materials, two of the sites reported a single instance when Total P or Ortho P was statistically highest when sulfur or polymer coatings were used.

- For the single green bean demonstration where sulfur coated fertilizer was evaluated, statistically similar yields and biomass were obtained with sulfur coated fertilizers with zero P and with uncoated fertilizers at a 40 P_2O_5 pounds per acre rate, suggesting a potential benefit of coated fertilizers for this crop. There were no statistical differences between soil P for coated and uncoated fertilizers. There were statistical significant increases in Ortho P levels during the life of the crop at application rates above 40 P_2O_5 pounds per acre rate.

Effect of pH amendments

- Results from only two tomato demonstrations were available for analysis. Statistically similar highest yields and biomass were obtained in the amended soils and non amended soils. The P_2O_5 rate to achieve these highest yields and biomass were similar with one exception. The lowering of soil pH increased biomass initially (30 DAT) but did not increase biomass or yield at the end of the growing season.

  These results can be explained by the effects of sulfur on soil pH during the life of the crop. While adding sulfur to the soil clearly lowered soil pH below 7.0 and would allow for greater availability of P left in the soil from previous crops, pH moderation lasted only 30 to 60 days. At harvest, the pH amended soil P was not significantly lower than in the non amended block, and the P_2O_5 rates resulting in statistically highest soil P levels were the same. An important recommendation of this demonstration is that lowering of soil pH with elemental S for tomatoes should not be encouraged as a practice to improve soil P availability because application did not result in biomass or yield increases.

  Regarding effects of pH amendment on water quality during the life of the crop, incidental statistically highest Ortho P and sulfur levels were observed for the Spring demonstration. However, statistically highest Ortho P and sulfur levels were consistently observed during the second year of the Fall site with application rates at (or above) 60 P_2O_5 pounds per acre and 125 pounds of elemental S.

- Results from only one green bean demonstration were available for analysis. Statistically similar highest yields were obtained with lower P rates when soils where amended (no P applied) than with non amended soils (40 P_2O_5 pound per acre were applied). However, results for plant biomass were the opposite. There was not a statistically significant difference between soil P for coated and uncoated fertilizers. Although there is a limited sample, these results may indicate the use of sulfur coated or elemental sulfur amendment for green beans as an opportunity to reduce P rates with no significant effects on yield.

Effect of Fertigation and Foliar Application:

- Effects varied between seasons although demonstrations took place in greenhouses. In the spring, the highest total extra-large yield and total yield were observed at 90 pounds per acre with fertigation and at 60 pounds per acre with foliar application. In the fall, the interaction between P rate and application method was not significant. The largest significant yield of extra-large fruit at first harvest, total extra-large fruit and total yield were all recorded at 120 pounds P_2O_5 per acre regardless of the application method.

- Leaf and stem biomass at the end of the season indicated that sufficient P was provided by the lowest P rates but 60 or more pounds P_2O_5 per acre were associated with the highest significant leaf and stem tissue P concentrations. Water quality samples at the end of the season indicated no significant difference in total P by P rate, application method or interaction of the P rate and method. However, mixed results were found for ortho phosphorus.

Soil Extractant, Sequential Analysis and Soil Test P Index Study:

- Previous extractant to soil ratios for Bray, Olsen and AB-DTPA were inadequate in soils with soil pH >6.5, extractable P >300 mg kg^{-1} and Ca > 1000 mg kg^{-1} and were revised. New extractant to soil ratios were developed and are proposed as part of this project.

- Sequential analysis indicated that water soluble and some bicarbonate extractable soil P are available and utilized by the crop plants.

- Use of multiple soil extractants indicated that Mehlich 1, Mehlich 3 and Bray extract water, bicarbonate and weak acid extractable forms of soil P, while Olsen and AB-DTPA extract water and some bicarbonate forms of soil P. Nevertheless, all extractants generally tended to underestimate water extractable P and water plus carbonate extractable P at levels above 150 mg kg^{-1} and 250 mg kg^{-1}, respectively.

- Correlations between the different extractants and water extractable P and water plus carbonate extractable P levels were not strong ($R^2 < 0.5$). The Mehlich 1 generally presented the highest correlation. However, there was not a substantial difference in the standard error among the soil extractants suggesting that it is the inherent variability of the soil P data which affects the strength of the correlation.

- A soil P index for high pH and calcium soils could not be developed based on data limitations. However, based on screening of the at planting Soil P data (without consideration of statistical significance) it appears that recommendations based on the Mehlich 1 extractant may need to be adjusted for tomato P_2O_5 needs at Soil P levels below 200 mg kg^{-1} for high pH and Ca soils (Figure ES5). Disregarding statistical significance considerations, it was observed that out of the 46 tomato yield data for the 13 demonstrations, percent relative yields were in the 90 to 100% top tier for 31 data points or 63% of the observations. Eighty percent (80%) of the top tier yields were observed at Mehlich 1 at planting Soil P levels in the range of 31 and 200 mg kg^{-1}. Fifty percent of the top tier yields were observed at Mehlich 1 Soil P levels below 150 mg kg^{-1}. The top tier yields were associated with all application rates. Note, also, that total relative yields below 90% were observed throughout the range of soil P levels at planting and were associated to all application rates indicating that extractable soil P in the range above will not ensure maximum yields under some conditions.

- Regarding calibration against pre-plant Soil P data, No potential increases in total yield with P_2O_5 application were discernible for pre-plant soil P levels below 123 mg kg^{-1}. However, total tomato relative yield appeared to increase with P_2O_5 applications up to 80 pounds per acre within 123 to 146 mg kg^{-1} pre-plant soil P levels, and with P_2O_5 applications up to 40 P_2O_5 pounds per acre for pre-plant soil P levels above 147 mg kg^{-1} (Figure ES6). These are preliminary indexes based on the limited dataset. In defining the upper end of the threshold, one may want to consider that eighty percent of the of the pre-plant soil P data for the demonstrations were below 165 mg kg^{-1} and that the Mehlich 1 exceeded the water plus carbonate extractable P in the majority of the observations at levels above 300 mg kg^{-1} Mehlich 1.

- A P index can be designed on a case by case index or as a universal index, which applies to all soils and all irrigation conditions. As noted in this study the concept of one index number fits all is very difficult particularly because the high pH and Ca soil chemistry interferes with plant P availability. The analysis provided in this report is a dedicated attempt to explain the available data and provides preliminary leads on thresholds that can be considered when making decisions. Regretfully, we do not have adequate information to go beyond this on a case by case basis for more conclusive results. Consideration of site specific conditions for each farm, including production and environmental risks, need to be taken into account when interpreting soil P data and making day to day decisions on P_2O_5 application.

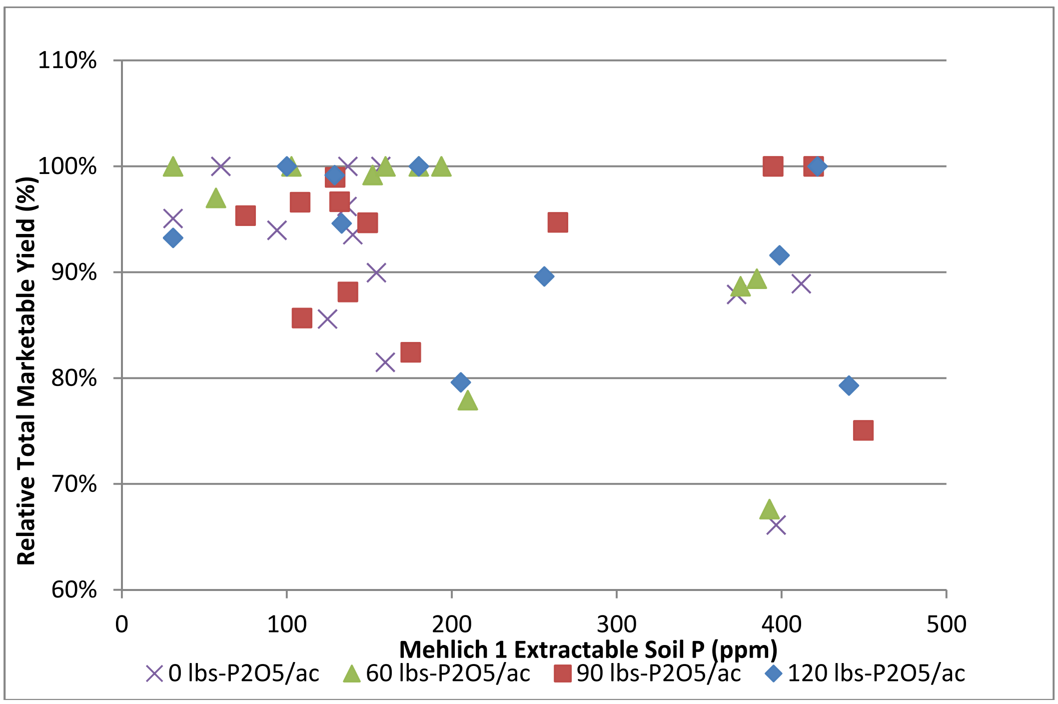

Figure ES 5: Relative Total Tomato Yield versus Mehlich 1 Soil P at Planting.

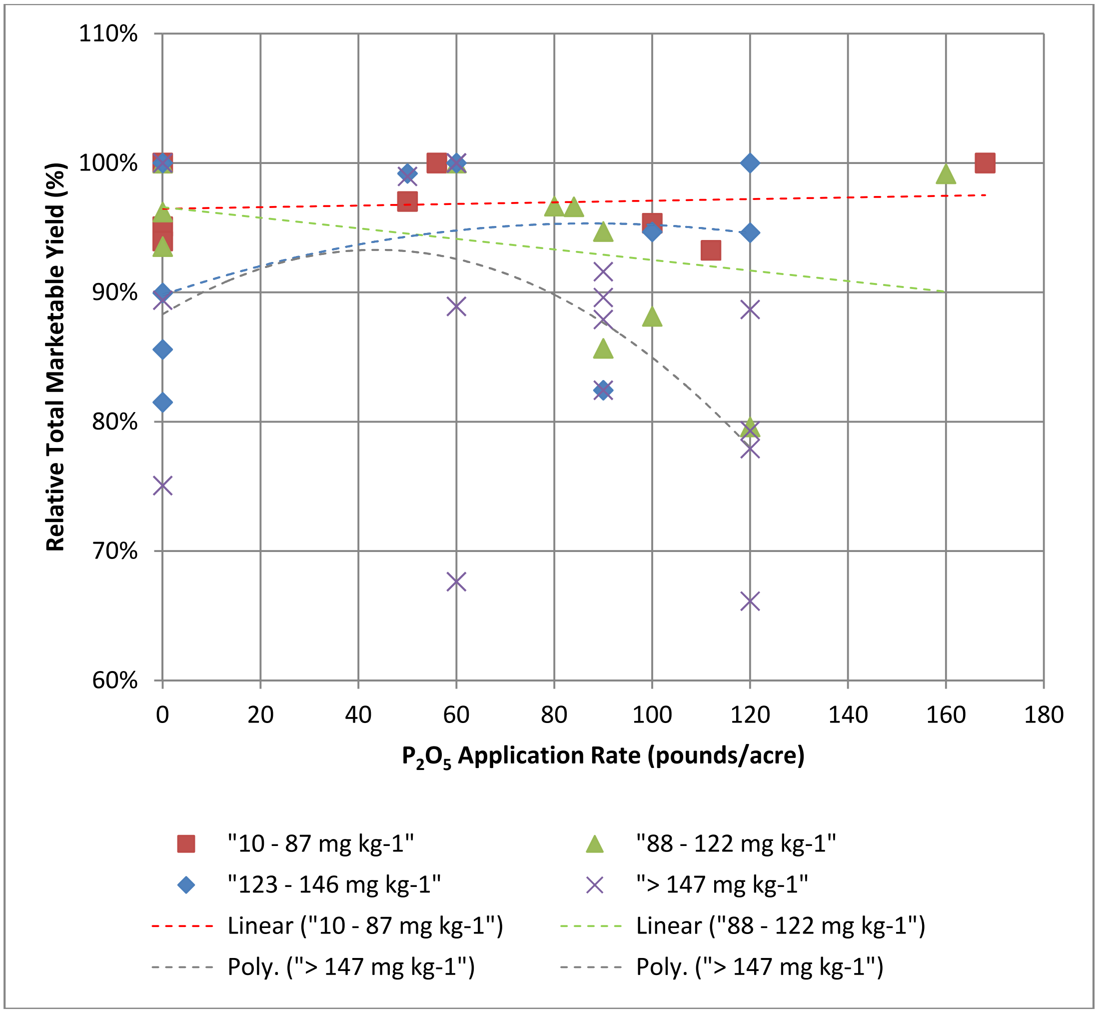

Figure ES 6: Relative Total Tomato Yield versus P2O5 Application Rate.

Table ES 1. Demonstration Sites Summary

Sites	First Phase Crop, P_2O_5 pounds per acre					Second Phase Crop, P_2O_5 pounds per acre, S pounds per acre, Coated fertilizers					
Farm	Spring 2006	Fall 2006	Spring 2007	Fall 2007	Spring 2008	Fall 2008	Spring 2009	Fall 2009	Spring 2010	Fall 2010	Spring 2011
1	Tomato P_2O_5: 0, 50, 100	Tomato Rates: 0, 84, 168		Tomato Rates: 0, 80, 160		Tomato P_2O_5: 0, 60, 90, 120 S: 0, 125, 250[2]		Tomato[1] P_2O_5: 0, 60, 90, 120 S: 0, 500, S coated		Tomato[1] P_2O_5: 0, 60, 90, 120 S and Polymer coated	
2	Eggplant P_2O_5: 0, 50, 100	Green bean P_2O_5: 0, 25, 50	Hot Peppers P_2O_5: 0, 50, 100	Green bean P_2O_5: 0, 30,60	Corn P_2O_5: 0, 50, 100	Green bean P_2O_5: 0, 40, 60, 80	Tomato P_2O_5: 0, 60, 90, 120 S: 0, 250, 500	Green bean[1] P_2O_5: 0, 40, 60, 80	Green bean P_2O_5: 0, 40, 60, 80 S: 0, 500 S coated	Tomato P_2O_5: 0, 60, 90, 120	Tomato P_2O_5: 0, 60, 90, 120 S and Polymer coated
3A	Tomato P_2O_5: 0, 50, 100	Green bean[3] P_2O_5: 0, 40	Tomato P_2O_5: 0, 50, 100	Green bean P_2O_5: 0, 25, 50	Green beans P_2O_5: 0, 25, 50	Tomato[1] P_2O_5: 0, 60, 90, 120	Green bean P_2O_5: 0, 40, 60, 80		Green[1] bean P_2O_5: 0, 40, 60, 80		Tomato P_2O_5: 0, 60, 90, 120
3B	Green bean P_2O_5: 0, 39	Green bean[3] P_2O_5: 0, 40	Green bean P_2O_5: 0, 40	Green bean P_2O_5: 0, 50	Green beans P_2O_5: 0, 50				Green bean P_2O_5: 0, 40, 60, 80		
4			Tomato P_2O_5: 0, 56, 112								
5						Bell Pepper[1] P_2O_5: 0, 60, 90, 120	Bell pepper P_2O_5: 0, 60, 90, 120				
6A								Tomato P_2O_5: 0, 60, 90, 120			
6B								Tomato P_2O_5: 0, 60, 90, 120			

[1]Crop substantially affected by weather effects. [2]Water quality monitored for this site. [3]Questionable data

Section 1: Fundamentals

1.1 Introduction

The C-139 Basin is a 170,000-acre agricultural basin in Hendry County and a tributary to the Everglades Protection Area (EPA). The Everglades Forever Act (EFA, Sections 373.4592(4)(f)5 and 6, Florida Statutes) mandates landowners within the C-139 Basin should not collectively exceed the average annual historic total phosphorus (P) loading. In 2002, the C-139 Basin Regulatory Program was created to ensure historic P levels are met based on mandatory implementation of Best Management Practices (BMPs), as defined in Rule 40E-63, Florida Administrative Code. Compliance with the water quality performance measure established by the EFA has not been consistently observed.

Soluble reactive phosphorus (SRP), typically associated with inorganic nutrient amendments has been identified as a major source of the P loading in C-139 Basin runoff (Community Watershed Fund 2007a and 2007B). SRP must be reduced to effectively reduce the P loads and meet EFA requirements. Based on regulatory program post-permit compliance results and the water quality studies referenced above, optimization of nutrient management practices in vegetable production have been identified as a crucial BMP for meeting the P load requirements.

This project was conducted under a six-year contract (OT051165) between the South Florida Water Management District (District) and the Florida Department of Agriculture and Consumer Services (FDACS) to administer and oversee development of a Vegetable Production Demonstration Project in the C-139 Basin by the UF-IFAS/Southwest Florida Research & Education Center in cooperation with C-139 Basin vegetable growers.

The main objectives of the project are to develop technical information to optimize nutrient management BMPs to prevent unnecessary application and P losses in runoff, and effectively disseminating this information. To achieve these objectives the following tasks were conducted:

1. Mapping the soils characteristics of the C-139 Basin vegetable farms, as described in the deliverable entitled “Summary Report of Soil Analysis, Mapping, Project setup and Water Quality Monitoring Plan”.
2. Demonstrating soil test-based P application rates based on the Mehlich 1 extractant when soluble P fertilizers are used.
3. Demonstrating the effectiveness, feasibility and effects on soils, water quality and crops of reducing soil pH levels to maximize the availability of historically accumulated P while reducing new application.
4. Same as Task 2, except that sulfur coated and polymer coated fertilizers were used.
5. Determine the effectiveness, feasibility, and effects on soils, water quality, and crops of increasing plant P use efficiency by splitting P application into weekly intervals via drip irrigation (fertigation) and foliar sprays.
6. Evaluating the most appropriate soil test method for vegetables in alkaline soils (pH>7.0) and calibrating the recommended application rate based on the preferred method.

7. Through education and extension services, reach out to all commercial vegetable growers in the C-139 Basin.

This final report considers all the data collected during the life of the project from the Spring 2006 to the Fall of 2011. Pursuant to the scope of work, the following information is included in this report:

- Section 1 discusses basic concepts related to nutrient management practices for vegetable production and demonstration project design.
- Section 2 provides an overview of the methods, sample sites and weather conditions during the project.
- Section 3 describes the effects of application P rate, soil pH amendments, and coated fertilizers on crop growth, P accumulation, and yield.
- Section 4 compares the Mehlich 1, Mehlich 3, Olsen, AB-DTPA, and Bray soil tests with preliminary calibration of a revised soil test P index for vegetable production in south Florida, and inclusion of soil pH consideration when providing P rate recommendations based on the soil test P index.
- Section 5 summarizes the dissemination and training initiatives carried on during the duration of this agreement. It also provides an update on the development of the UF-IFAS Cooperative Extension Service Fact Sheet summarizing this project.
- Section 6 provides conclusion and recommendations. Growth and yield response curves for the alternate treatments are presented based on applied P rates at selected soil pH and sulfur application rates. It discusses factors to consider when developing fertilizer rate recommendations (including those warranting deviation from standard recommendations) and any additional information that may be needed to further calibrate/optimize the soil test P index.

1.2 Background

1.2.1 Soil Testing

Soil testing as an index of P availability for Florida vegetable production has existed for more than 30 years. A soil test allows the grower to accurately predict soil P availability and adjust P fertilizer rates. For selected plant nutrients, UF-IFAS has developed a range of nutrient specific soil concentrations into classifications called indexes of very low, low, medium, high and very high using data collected under field conditions. The range of nutrient concentrations in the soil are based on growth and yield response to a wide range of nutrient fertilizer applications in a large number of field studies. The exact nutrient amounts applied and number of field studies used vary by nutrient and crop, but must be performed over at least a three year period and result with statistically valid data to determine a crop response curve. The response curve has soil nutrient concentration or addition on the x-axis and crop growth or yield on the y-axis (Figure 1).

Typically, crop growth or yield increases with increased nutrient application to a point where the curve flattens and no significant increase in growth or yield is discernible. This point is considered the recommended fertilizer rate for a given starting soil concentration or index. The field conditions are as close as possible to weather, soil characteristics, water management, and horticultural practices most growers would use. In most cases, the experiments are conducted in grower fields or at UF-IFAS experiment stations. A high or very high soil test index indicates no increased yield response is likely to result from added fertilizer. The other three indexes (very low, low and medium) have nutrient recommendations specific for each index and crop. Thus, the very low, low, medium, high, and very high index ranges for P are <10, 10-15, 16-30, 31-60 and >60 mg kg^{-1}, respectively with fertilizer recommendations of 150, 120, 100, 0 and 0 pounds P_2O_5 per acre, respectively (Table 1).

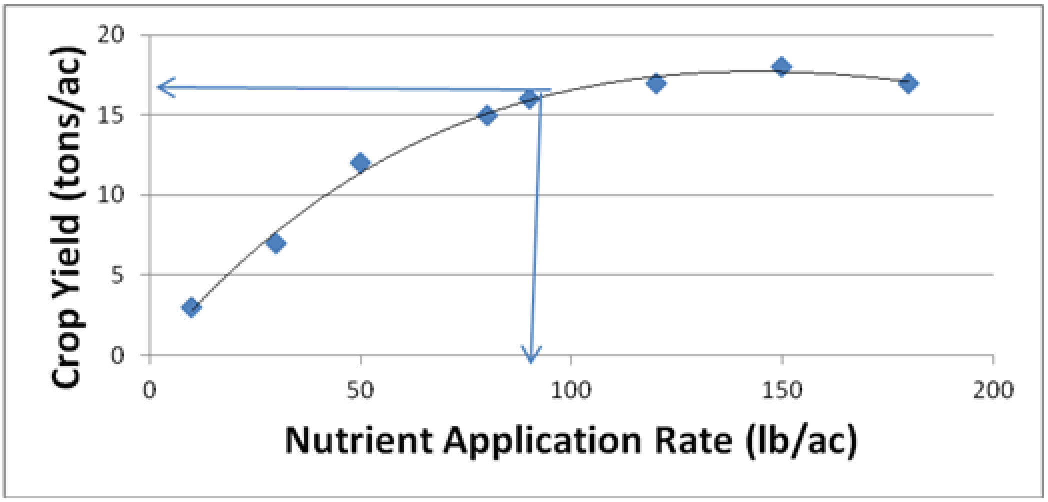

Figure 1. Generic yield response curve arrows indicating relationship between nutrient application rate (x-axis) for maximum yield (y-axis).

Table 1. Soil Sample Analysis Index Using Mehlich 1 Extractant

Nutrient	*Very Low*	*Low*	*Medium*	*High*	*Very High*
	Parts per million soil				
Phosphorus (P)	<10	10-15	16-30	31-60	>60
Potassium (K)	<20	20-35	36-60	61-125	>125
Magnesium (Mg)	<10	10-20	21-40	41-60	>60
Ca	<100	100-200	201-300	301-400	>400
	P fertilizer Recommendation (lb P_2O_5 ac^{-1})				
All vegetable crops	150	120	100	0	0

Source: Olson, S.M. and E. Simonne. 2007. Vegetable Production Handbook for Florida 2006-2007. UF-IFAS.

1.2.2 Soil Extractants and Sequential Analysis

Soil samples were collected prior to planting and at approximately 30 day intervals during crop growth from the center of the row, in line with plants, at 10 to 15 locations per plot, to a depth of 0 to 6 inches using a ¾ inch soil auger. The 10 to 15 sub-samples per plot were then combined into one sample and analyzed for P content using the Mehlich 1, Mehlich 3, Olsen, Bray and AB-DTPA extractants. The type of extractant used for soil testing influences the amount of P extracted from the soil and thus, the estimate of plant P availability. Soil pH has a great impact on the chemical form of P in the soil and should be considered for selecting the most appropriate extractant.

For example, at pH below 7.0, P will be readily soluble and the extractants used in this project should extract similar amounts of P. However, in soils with high Ca concentrations and pH greater than 7.0, a portion of soil P will precipitate in the form of various Ca phosphate compounds. These compounds dissolve in acid solution but are not available for plant uptake. The preferred soil pH for vegetable production is about 6.0 to 6.5, but as determined in the first phase of this project, many soils in the C-139 Basin range from 7.0 to 8.0 and at times even highest. Growers control soil pH with the type of fertilizer they use. Lime or dolomite may be used if the soil pH is too low to raise pH or sulfur to lower pH if the soil pH is too high. Some soil testing laboratories report pH according to the solution used to extract from the soil sample. If water is used, then it is reported as pH_w. If buffered solution is used, then it is reported as pH_g and these values are used to determine liming requirements. For the purposes of this report, values of pH_w are adequate and sufficient.

Since the UF-IFAS recommendations are based on the Mehlich 1 extractant (Table 1). Soil P measurements using Mehlich 1 were compared with the other four extractants and with the estimate of plant available P using a sequential analysis. Sequential analysis determines the amount of P in a soil at increasingly less available forms to the plant. The most readily available form of P is the water soluble P followed by carbonate extractable forms. However, not all carbonate P forms are readily available to plants. Thus, extractants providing soil P concentrations similar to or greater than the sum of water and carbonate extractable P over estimate the amount of P available to plants. Sequential analysis provides insight into the correlation among the extractants and the plant available P in soil solution.

1.2.3 Plant Biomass, Tissue Phosphorus, and Yield

To collect adequate crop tissue P and biomass data, samples were taken at regular intervals throughout the growing cycle.

Biomass - A measure of plant performance is biomass accumulation. This is the dry weight of plant material. Plants are cut at the soil surface, removed from the field, separated into leaves, stems, and fruit; dried in an oven until all water content was removed and its dry weight measured. Biomass was determined at about 30-day intervals during the growth of the crop. Biomass accumulation was estimated based on a 10 foot segment of row. Tomatoes are typically planted 1 foot apart, so 10 plants represent 10 feet of row. For tomato, 10 plants were selected at random at each sample date in each treatment area. Green beans are seeded into the row and thus the number of plants per 10 feet of row can vary greatly. To determine green bean biomass, the number of plants in a 10 foot segment of row was counted and 10 representative plants were collected. Total green bean biomass per 10 feet of row was estimated by multiplying the number of plants per 10 feet of row by the average dry weight per plant.

In general, plants produce the most biomass when they are grown under conditions of high available soil nutrients. When conditions are less than optimum (i.e. when stressed in any way), biomass accumulation normally suffers. Thus, it is important that conditions for growth are optimum so plants can grow as large as possible while, at the same time, maintain high yields. This is yet another example of how biomass is an indirect measure of plant productivity. However, when the nutrient rates to produce high yields are lower than the rates producing the most biomass (e.g., leaf biomass), an excess of nutrient application may be indicated.

Plant tissue phosphorus concentration and plant P accumulation - Nutrients accumulate in plant tissue at different rates and different concentrations depending on the nutrient, the plant tissue, growing conditions, stage of growth and availability to the plant. If unavailable in sufficient amounts, plant tissue concentration will be deficient for optimum growth, productivity, and result in morphological abnormalities. Plants collected for biomass measurement were also ground and analyzed chemically for P. Leaves are typically used to indicate the nutrient status of the crop plants at the time the samples are taken. To estimate P uptake with time, total plant P accumulation was calculated by multiplying the dry plant tissue weights per plant (including leaves, stems and fruit) by the P concentrations of each tissue. Adequate P tissue levels are presented in Table 2.

Table 2. Sufficiency Range of Plant Nutrients Based on Crop Growth Stage.

Crop [z]	*Stage of growth*	*Sufficiency range (% P on dry weight basis)*
Tomato	5-leaf stage	0.3 to 0.6
	First flower	0.2 to 0.4
	Early fruit set	0.2 to 0.4
	First ripe fruit	0.2 to 0.4
	During harvest period	0.2 to 0.4
Pepper	Early bloom	0.3 to 0.5
Green bean	First bloom	0.3 to 0.4
Eggplant	Early fruit set	0.3 to 0.6
Corn	Early fruit set	0.2 to 0.5

[z]Hochmuth, Maynard, Vavrina, Hanlon, and Simonne. 2004. Plant tissue analysis and interpretation for vegetable crops in Florida. UF/IFAS

Yields - Yield is the most important measure of plant performance. Yield is a direct measure of plant productivity. It is measured only for the portion of the crop removed from the field (fruit) and sold for economic gain. There are several categories of yield for fruit crops (e.g., tomato). Total yield is a measure of all marketable fruits or harvests the plant can produce, also referred to as Marketable Yield, and is the portion of yield considered saleable. In the case of a tomato crop, marketable tomatoes are fruits with little or no defects. Culls or unmarketable yield is the portion of total yield not saleable and is composed of vegetables not harvested, discarded because of insect or disease damage, or culled because of size or blemish.

Tomato: The tomato crops in this studies were of the “large round” red type and grown for the “gas-green” market. Gas-green means the tomatoes are picked at the mature green stage and then sorted by size and quality in packing sheds. At the sheds, tomatoes are boxed according to size and quality and then gassed with the natural ripening compound ethylene. After several days of storage, depending on market demand, pallets of boxes are shipped by truck to distant markets. The traditional USDA size categories are medium, large, and extra large. These correspond to industry size categories of 6x7, 6x6, and 5x6. The terms were established by the industry and have been developed according to how many of each category can fit in a box. However, boxes used by the industry change over time and these sizes may no longer represent what fits into a standard box. Currently, an industry box has inside dimensions of 14.75 inches long by 11.50 inches wide and 8.75 inches tall. These boxes hold approximately 25 pounds of tomatoes regardless of size category.

The 10 plants within a row of each treatment plot were selected prior to harvest of the field. The fruit determined mature by visual inspection were removed from each of the 10 plants and separated into the three size categories and culls. The fruit were weighed to determine the fresh fruit weight per size per 10 plants. Harvests are typically done each 7 to 10 days and a total of three harvests per farm were attempted but not always possible due to weather conditions or plant injury. Yield estimated in the manner described above is representative among treatment plots but usually underestimates yields reported by growers because growers typically concentrate on picking the largest size fruit each harvest and allows the smaller sized fruit to increase in size. Another source of difference in grower reported yield is when boxes are calculated using 10 feet of row assumes 25 pounds of fruit per box when growers deliver fruit in bulk and the weight of fruit per box may be more or less than 25 pounds.

Green bean: The growers in this project used “mechanical combines” harvesting four rows at a time (two rows of plants on each of two plant beds). Green beans are harvested when the beans developing first on the plant are the correct size. This ensures that most of the rest of the beans on the plant are also ready to harvest. Bean plants must be healthy and strong enough to support the crop so that soil does not come in contact with the beans. This ensures a clean crop and prevents losses from disease and decay. Beans must be supported high enough in the canopy so that the combine can harvest the crop without picking up sand and debris. Plants must also be strong enough to withstand combining without shattering or pulling out of the ground. Marketable beans are mostly 4 to 6 inches long and straight or almost straight. All plants in a 10 foot length of row were harvested in one harvest at approximately the same time as the rest of the field. The beans were separated into three size categories by length (4-6 inches, 3-4 inches and less than 3 inches) and weighed.

Bell Pepper: Peppers were grown on double row beds (i.e. two rows planted in the same space as one row of tomatoes). Harvests were conducted at the same time as harvest of the treatment field, with 10 feet of row per treatment plot chosen before harvest. Harvested peppers were divided into size categories based on fruit diameter with Fancy >5 inch, US1 3 to 5 inches, and US2 less than 3 inches.

Eggplant: Eggplants were grown in a single row of plants on mulch covered rows. Three harvests were conducted from the same 10 feet of row from each treatment plot the day prior to commercial harvest. The number and weight of marketable and culled fruit were measured.

Hot Peppers: Two varieties of hot peppers (Jalapeno and Cubanello) were planted in double rows of plants on mulch covered beds. A total of five harvests were conducted of both varieties from the same 10 foot row segments per treatment plot prior to commercial harvest of the field. Total fruit weight and number of fruits per harvest of each variety were recorded.

Corn: Corn was grown in single rows without plastic mulch. A single harvest of 10 foot row segments from each treatment plot was conducted the day prior to commercial harvest of the rest of the field. The weight and number of fruit or 'ears' from each 10 foot row segments were recorded along with the weight and number of cull ears.

1.2.4 Fertigation and Foliar Application

The experimental design was a randomized complete block (RCB) of two P application methods at four seasonal P application rates with each combination replicated four times. Plots consisted of a single soil container 3 feet long by 2 feet wide containing three tomato plants each. Soil from Farm 1 was packed to the same conditions (i.e. bulk density and horizon thickness) found in the field. The top of the container was bedded with plastic mulch to simulate field conditions.

Half of the containers included drip irrigation tubing adjacent to the tomato plants under the plastic mulch, as it would be installed in the field. The drip irrigated containers were fertigated based on plant size adjusted weekly through the season using UF-IFAS recommendations for water proportionally to the P rate in the field demonstrations (0, 60, 90 and 120 pounds per acre). Foliar sprays were sprayed weekly by hand using the same P amounts as for fertigation. Irrigation of these containers simulated seepage by maintaining the water level in the container at 18 inches below ground surface. A drainage system was installed prior to planting to remove excess water. Water samples were analyzed for TP and Orthophosphorus (Ortho P). Plant tissue was collected at 30 day intervals by sampling 10 random leaves from each container at each sample date. Biomass estimates during the life of the crop at 30 day intervals were provided by counting leaves and measuring plant size. Final biomass weights were determined for all plants used in the study by separating the plants in to leaves, stems and roots. Yield was determined by harvesting all fruit from all plants per container for three harvests at the end of the season.

1.2.5 Coated Fertilizers

Demonstration projects included the analysis of the effects of sulfur coated and polymer coated fertilizers along with standard soluble fertilizer as a control. Sulfur coated P fertilizer materials will slowly release S into the soil solution during the growing season and moderate (lower) the soil pH in the immediate vicinity of the fertilizer pellet. Once the P in solution comes in contact with soil Ca, precipitation can occur but the slow release should provide available P for a longer period of time. Likewise, the application of polymer coated phosphorus will release slowly into the soil allowing for more efficient uptake of P prior to precipitation. For both sulfur coated and polymer coated materials, P was applied at the same rates as for the soluble fertilizer demonstrations.

1.2.6 Statistical Analysis

Agricultural experiments are often designed in such a way that data collected during the experiment can be statistically analyzed. Experimental designs and statistical analyses are as varied as the experiments themselves, but what is common to most experiments is the ability to test for statistically significant differences. When confronted with numbers having different values, researchers often ask the question, "Are these differences real?" this is the same as asking, "Are the differences significant?" Statistical analyses allow researchers to answer the question. Statistical analyses require that experiments have appropriate experimental designs and replication of treatments. In most of the demonstration plantings reported here, the experimental design used was a RCB design. This is a common experimental design used in agriculture. Treatments must be replicated for analysis to be possible. There must be at least two replications of treatments but three or four replications are preferred. The split plot experimental design (SPED) was chosen to reduce variation from site conditions related to soil characteristics and water movement by applying one treatment per block across the demonstration area. By having all treatments in each of several blocks, the likelihood of significant impact of block on treatment results was not greater for one treatment compared with another treatment, therefore reducing the likelihood of a significant treatment/block interaction term. In the event of a significant treatment/block interaction the multiple comparisons should not be used.

When reporting results from experiments in the demonstration project, differences among treatments are considered statistically significant at probability levels of "*0.050*" or less. This is the most common threshold of significance used in agricultural research and means there is a 95% probability the values being reported are truly different. Or in other words, the values likely come from at least two different populations of numbers and there is only a 5% probability the values come from the same population of numbers.

For all data, Duncan's multiple range test was used for separation of means. Values reported in tables are traditionally labeled with lettering such as "a", "ab", and "b" to designate significant differences among treatments. Values having letters in common are not significantly different. For example, values labeled "a" are not statistically different from values labeled "ab" but are significantly different than values labeled "b". Values without lettering are not significantly different at the 0.05 level. When possible, significance levels are reported.

When a treatment, e.g., a rate, coating, pH amendment, application method or combination are referred as being statistically or significantly highest, it means that they are associated with the top tier of response (e.g., yield, biomass, P accumulation, Soil P, water quality levels). When more than one treatment is associated with the statistically or significantly highest levels, these are being referred as being statistically similar highest levels. Since the purpose of the project is to optimize nutrient management BMPs to prevent unnecessary application, when more than one treatment achieves the statistically or significantly highest levels, the lowest P application rate associated to the top tier of response is indicated.

Section 2: Methodology

2.1 Farm and Crops

In 2005, the first phase of the project was initiated. The UF-IFAS research team was comprised of two horticulturists, two soil scientists, and one extension agent. The sample consisted of four farms participating in the demonstration project with one or two demonstrations each. There were 19 demonstration plantings between 2006 and 2008, as indicated in Table 3. The Spring 2008 season consisted of only 3 sites because of unexpected cancellation of Farm 4. The demonstration project designs were set up at the beginning of the growing season, and crops were grown by each grower following their own production practices.

Table 3. Crops Grown in Production Plots: Spring 2006 to Spring 2008.

Farm	Spring 2006	Fall 2006	Spring 2007	Fall 2007	Spring 2008
1	Tomato	Tomato		Tomato	
2	Eggplant	Green beans	Peppers	Green beans	Corn
3A	Tomato	Green beans	Tomato	Green beans	Green beans
3B	Green beans	Green beans	Green beans	Green beans	Green beans
4			Tomato		

In the fall of 2008, the project was expanded into a second phase with larger scope. Eighteen (18) demonstrations were installed during six growing seasons as presented in Table 4. The number of sites during the fall 2010 and spring 2011 were reduced to two crops per season to allow for the lysimeter studies located in greenhouses at Southwest Florida Research and Education Center (SWFREC) in Immokalee. The demonstration project focused on tomatoes, but green bean and bell pepper crops were also produced at the initiative of the participating farmers. The experimental design for each farm is detailed in Deliverable 2 entitled "Soil Analysis, Mapping, Project Setup and Water Quality Monitoring Plan for the C-139 Basin Vegetable Demonstration Project".

Table 4. Crops Grown in Production Plots: Fall 2008 to Spring 2011.

Farm	Fall 2008	Spring 2009	Fall 2009	Spring 2010	Fall 2010	Spring 2011
1	Tomato	(1)	Tomato	(1)	Tomato	
2	Green beans	Tomato	Green beans	Green beans	Tomato	Tomato
3A	Tomato	Green beans		Green beans(4)		Tomato
3B				Green beans(4)		
5(2)	Bell Pepper	Bell Pepper				
6A(3)			Tomato			
6B			Tomato			

(1) No crops were grown at Farm 1 and substitutes could not be found.
(2) Farm 5 ended its lease after the spring of 2009 and stopped participation.
(3) Farm 6 stopped participation after 2009
(4) Two locations at Farm 3 were used to substitute for farms 5 and 6.

Production practices for tomato and green bean crops are site specific, that is, every grower has their own method and procedure for establishing their crop and obtaining high yields of high quality produce. It is not the intent of this report to detail these production practices. Information about basic practices, shared in common with most growers, is found in the University of Florida publication "Vegetable Production Handbook for Florida 2006-2007". The Handbook is updated every year, and individual chapters of the Handbook are available online at http://edis.ifas.ufl.edu/cv101.

2.2 Fertilizer Rates

For the first phase, the experimental design was a RCB with three replications at three rates: grower's typical application rate (full rate), half full rate, and UF-IFAS recommendation (No P applied based on observed high P soil test levels). The fertilizer rates used each at each demonstration planting are presented in Table 5.

Table 5. Fertilizer P Rate: Spring 2006 to Spring 2008.

	Spring 2006	Fall 2006	Spring 2007	Fall 2007	Spring 2008
	Fertilizer P rate[Z] (lbs/ac)				
Farm 1 (only Tomato)					
Zero rate	0	0		0	
Half rate	50	84		80	
Full rate	100	168		160	
Farm 2					
Zero rate	0	0	0	0	0
Half rate	50	25	50	30	50
Full rate	100	50	100	60	100
Farm 3a[Y]					
Zero rate	0	0	0	0	0
Half rate	50	-	50	-	-
Full rate	100	40	100	50	50
Farm 3b (only Green Beans)					
Zero rate	0	0	0	0	0
Full rate	39	40	40	50	50
Farm 4 (only Tomato)					
Zero rate			0		
Half rate			56		
Full rate			112		

[Z] Fertilizer rate varied from season to season with crop grown and production practices of the grower/cooperator.
[Y] Tomato crops at farm 3a had three P rates: green bean crops had only two P rates.

In the second phase, the RCB experimental design was expanded to include four replications. Each block contained three to six rows of 300 to 500 feet of plants per row for the main P rate treatment. The P application rates were to be 0, 50, 75, and 100% of current UF-IFAS recommended rates using low soil test P index recommendations for the respective crop grown (Table 6).

Blocks were divided into subplots to demonstrate fertilizer types or pH amendments. The minimum subplot size was 3 rows each 50 feet in length. Subplots contained one of the following: a) soluble P fertilizer, b) soluble fertilizer with one of two rates of elemental S, c) sulfur coated P fertilizer, or d) polymer coated P fertilizer in the bottom mix all at the same P rate.

Table 6. Target P_2O_5 Treatment Levels Based on IFAS Recommended P Rate Using Low Soil Test P index as Recommendation.

Crop	Target P_2O_5 Rates Using Low Soil Test P Recommendations			
	0%	50%	75%	100%
	Pounds of P_2O_5/acre			
Tomato	0	60	90	120
Green Pepper	0	60	90	120
Green beans	0	40	60	80

2.3 Water Quality Monitoring

During the second phase, water quality sampling was conducted at sites where pH amendments using elemental sulfur (S) or coated fertilizer (sulfur or polymer coated fertilizer) were demonstrated to estimate the levels of total phosphorus (TP), ortho phosphorus (the majority of it expected to be SRP), sulfates, specific conductivity and pH associated with the different treatments and P rates. Water quality samples were collected at 30 day intervals and within 72 hours of a 1.25 cm rainfall event at the drainage ditches adjacent to the treatment subplots. Rainfall was monitored using the Florida Automated Weather Network station located at the SWFREC in Immokalee. A summary of the demonstrations where water quality was collected are presented in Table 7.

Table 7. Demonstration Sites with Water Quality Collection: Fall 2008 to Spring 2011.

	Fall 2008	Spring 2009	Fall 2009	Spring 2010	Fall 2010	Spring 2011
Farm	1	2	1	2	2	2
Crop:	Tomato	Tomato	Tomato	Green beans	Tomato	Tomato
Treatments:	pH (0, 125, 250 S lbs/acre)	pH (0, 250, 500 S lbs/acre)	pH (0, 500 S lbs/acre) S coated fertilizer	pH (0, 500 S lbs/acre) S coated fertilizer	S coated fertilizer Polymer coated fertilizer	S coated fertilizer Polymer coated fertilizer

The water quality results represent discharges during the growing season, which being the dry season only represents limited discharge. The effect of the different treatments and P rates will likely not be fully captured until the wet season begins, water levels will rise, and discharge pumps will mobilize any leftover P. This water quality collection effort provides only a relative indication of the differences among treatments, as a first step in obtaining a complete picture in understanding the effect of alternate nutrient management practices on water quality, as well as on yield, biomass and soil P levels. It may be necessary, however, to reconsider the experiment design and methods for water quality collection in future evaluations.

2.4 Weather Conditions

Weather conditions affect the agricultural industry every year and were prominent during the second phase of the demonstration project. Their effects ranged from site to site based on various conditions (e.g., plant date). Out of the 37 demonstrations covered from the Spring of 2006 to Spring 2011, six (6) were considered to be substantially impacted by weather effects. Table 8 provides a summary of the weather effects on the demonstrations.

Fall 2008 – Spring 2009: Farms planted prior to the landfall of Tropical Storm Fay on 19 August 2008 were almost completely destroyed. Rainfall recorded by the Florida Automated Weather Network (FAWN) at Immokalee and Clewiston were 7.3 and 7.9 inches, respectively. Many fields remained under water for as long as two weeks. Most of the fields that were bedded or bedded and planted prior to 19 August had their plastic mulch removed, soil leveled, bedded and planted a second time. The aftermath of Tropical Storm Fay delayed planting of demonstration plots by about six weeks delaying the fall harvest demonstrations to January and February. Three freeze events occurred on: 20-23 January 2009 (with lows of 25.2 and 28.8 degrees Fahrenheit in Immokalee and Clewiston, respectively), 5 February 2009 (with lows of 24.7 and 28.1 degrees Fahrenheit in Immokalee and Clewiston, respectively) and March 3, 2009 (with lows of 29.4 and 33.3 degrees Fahrenheit in Immokalee and Clewiston, respectively).

Fall 2009 – Spring 2010: Ten consecutive days with temperatures at or below freezing occurred from January 4th to the 13th, 2009. Temperatures as low as -4.3 and -3.5 degrees Celsius were reported on January 11, 2010, in Clewiston and Immokalee, respectively. Freeze events resulted in crop loss and/or delay in harvest for Fall to Winter crops reducing the number of harvests per crop, crop quantity per harvest and crop quality or fruit size.

Fall 2010 – Spring 2011: Five freeze events (December 7, 14 and 27, 2010, and January 13 and 23, 2011), were recorded at the FAWN Immokalee station. The coldest temperatures recorded at the Immokalee station was -3.9 degrees Celsius, on December 14, 2010. The duration of freezing temperatures in 2010/2011 was shorter than during the winter of 2009/2010 (2 days); however, frost was reported in Hendry County on multiple dates including the freeze event dates listed above. Freeze and frost events resulted in crop loss and/or delay in harvest for Fall to Winter crops, reducing the number of harvests per crop, crop quantity and quality per harvest or fruit size. Harvests were delayed by 30 days or more to late February to allow the plants to set new fruit because the fruit on the plants were damaged by the frost and were unmarketable at both Farms. No freezing conditions occurred at the SWFREC FAWN site after February 1, 2011, but the spring was unusually dry with only 8.4 inches of rain from February 1 to June 1, 2011compared with 24.27 inches for the same period in 2010. The lack of rainfall was compensated for by increased water use (conversations with growers) in seepage irrigation.

Table 8. Summary of Weather Effects by Farm.

Farm	Fall 2008		Fall 2009		Spring 2010		Fall 2010	
	Effects	Total Yield[1] (boxes per acre)	Effects	Total Yield[1] (boxes per acre)	Effects	Total Yield[1] (boxes per acre)	Effects	Total Yield[1] (boxes per acre)
1	Tomato plant replanted after Fay. Second planting not affected	1,981	Tomato plants substantially affected by freeze	972[2]			Tomato plants substantially affected by freeze	964[2]
2	Green bean plants partially affected by freeze	152[3]	Green bean plants destroyed by freeze	175[2]			Tomato plants partially affected by freeze	1,372[3]
3A	Tomato plants partially affected by freeze	1,192[2]			Green bean plants partially affected by freeze	154[2]		
5	Bell Pepper	258[2]						

[1]Statistically highest total yield at lowest application rate.
[2]Removed from overall evaluation because of substantial effects.
[3]These crops were considered for the overall evaluation because they were within 10% of the average yield for this crop despite partial weather effects. Average yield for tomatoes is approximately 1,400 boxes per acre and for green beans is approximately 200 boxes per acre.

Section 3: Field Demonstration Results

3.1 Demonstration of Soil Test-based P Application Rates

This section discusses the effects on yield, biomass, crop growth, P tissue accumulation and soils of using alternate rates of soluble P fertilizers based on the 24 tomato and green beans demonstrations evaluated during the 2006 – 2011 growing seasons, as presented earlier in Tables 3 and 4. Questions were developed to summarize the findings. In order to consider statistical significance, the lowest P rates resulting in the significantly greater yield, biomass, P tissue levels, and soil P are provided in Tables 9 - 13. Questions and answers are indicated next:

1. Did total or total extra large yields increase with P rate of soluble fertilizer?

Yields statistically increased with P application rates only for some demonstrations. For tomatoes, when statistically highest yields were observed they were generally with rates lower than the grower typical rates or the rate assuming low soil P (approximately 120 lbs/acre). For green beans, when statistically highest yields were observed they could be observed with rates up to the grower typical rate or the rate assuming low soil P (approximately 50 lbs/acre). Note that for all demonstrations covered in this project, soil P at planting was measured at or above high levels based on the Mehlich 1 extractant (31 mg kg^{-1} P). A discussion of soil P conditions based on plant available P is presented in Section 4 covering soil extractants and sequential analyses. A detailed description per phase and crop follows:

Tomato: Five (5) participating farms including sixteen (16) demonstrations were evaluated. Three (3) of the sites were substantially affected by weather, as presented earlier in Table 8 and results are not representative. Results for the representative sites varied, as discussed next:

- In the first phase, when only three replicates were used, only one of the six sites produced statistically significant yield results (Farm 1). These results indicated that significantly highest total yields were obtained with no P applied in comparison to the grower typical application (100 pounds of P_2O_5/acre) or half the typical application (50 pounds of P_2O_5/acre). No statistically significant yields of extra large fruit were found for any site (Table 9).

- In the second phase, when four replicates were used, the average P rate producing the statistically significant highest total and total extra-large yields were 90 and 60 pounds of P_2O_5 per acre of soluble fertilizer, respectively (Table 10). Out of the seven representative sites, four had statistically significant yield data for both total extra large fruit and total fruit while two others had statistically significant yield data for either total extra large fruit or total fruit

Green beans: Two (2) participating farms including sixteen (16) demonstrations were evaluated. Data from two (2) sites in the first phase was found questionable (identical statistical results and unavailable raw datasets). Also, two sites in the second phase were substantially affected by weather and results are not representative. Results for the representative sites varied, as discussed next:

- In the first phase, when only three replicates were used, consistent statistically significant effects on yield were only found for Farm 3B. However, each farm had at least one demonstration with statistically significant data. Out of the eight representative demonstrations, statistically significant results for either total yield or large pod yield were determined in five. The average application rates resulting in statistically significant highest total and large pod yield were 40 and 50 pounds per acre P_2O_5 (Table 11), respectively.

- In the second phase, when four replicates were used, statistically significant effects on yield were only found for Farm 2. Out of the four representative demonstrations, statistically significant highest total yield and large green bean pod size were obtained at 60 pounds of P_2O_5 per acre (Table 12).

2. Did leaf, stem or fruit biomass increase with P rate of soluble fertilizer?

Not consistently. Contrasting results for tomatoes and green beans were found during the first phase, while a statistically significant effect was observed for tomatoes during the second phase of the project with highest total biomass and leaf biomass at 60 and 90 pounds of P_2O_5 per acre, respectively. Statistically significant effects for green beans were only observed during the first phase of the project.

Tomato: Total above ground biomass was sampled in the first phase and the first two years of the second phase. Afterwards, biomass was separated into leaf stem and fruit segments and weighed separately.

- As with yield during the first phase, only Farm 1 had one statistically significant result indicating that statistically highest total biomass was observed with no P_2O_5 applied (Table 9).

- In the second phase of the demonstration, five of the seven representative demonstrations had statistically significant total biomass results. The rates resulting in statistically highest total biomass varied from site to site from 0 to 90 pounds of P_2O_5 (Table 10). In the third year of the second phase (Fall 2010 and Spring 2011) when biomass was separated into component plant parts, significantly highest leaf biomass was observed with a varied range of application rates. The average lowest soluble fertilizer P rate required to produce significantly highest total biomass or leaf biomass was 60 and 90 pounds of P_2O_5 per acre respectively.

Green beans: Total biomass in the first phase of the demonstration was significantly greater in six of the eight sites at a rate of 40 pounds of P_2O_5 per acre, on average (Table 11). In the second phase of the demonstration, despite the increase in replicates from three to four, there was no significant increase in total plant biomass, plant stand or leaf P with increase in P_2O_5 rate in any of the four demonstrations not substantially affected by weather (Table 12).

3. Was soil P highest with increased P rate of soluble fertilizer?

Based on the Mehlich 1 extractant, statistically highest soil P levels at harvest were observed at application levels of 50 P_2O_5 pounds per acre and highest for tomatoes. For green beans, which use lower application rates, no consistent results were obtained.

Tomato:

- In the first phase, statistically significant differences among the tomato demonstrations could only be identified for two of the six demonstrations prior to planting (prior to P_2O_5 application). At harvest, however, three sites recorded statistically highest soil P levels in plots receiving 50 pounds of P_2O_5 per acre or highest. In addition, one of the sites continued to record statistical differences at harvest, however, at lower rates. Only one of the sites did not record statistical differences at harvest while it did at planting. For the farms with statistically significant results, highest soil P levels were obtained at the half full rate, and highest, in comparison with no P applied. The half full rate varied from farm to farm but was as low as 50 pounds of P_2O_5/acre. There were no statistically significant improvements in yield concurrent with the statistically significant increases in soil P (Table 9).
- In the second phase and on an individual farm basis, significantly highest soil P concentrations at harvest were observed at soluble P rates of approximately 90 pounds of P_2O_5 per acre and highest. For these farms the rates associated with the statistically highest soil P levels at planting were similar, lower or not statistically significant. Therefore, in contrast with the first phase, it would appear as the effect of varying P application rates during the individual growing seasons can, but does not always, statistically affect soil P levels at harvest despite pre-plant conditions. On average for the representative sites, significantly highest soil P was observed at approximately 120 pounds of P_2O_5 per acre (Table 10).

Green beans:

- In the first phase of the demonstration project, four of the eight representative demonstrations did not have statistically significant differences in soil P at planting, but one of these resulted in statistically significant soil P at harvest with a rate of 25 pounds of P_2O_5 per acre. Of the four sites with significant differences in soil P at planting, three reported no statistical significant differences at harvest or maintained the differences observed at planting (Table 11).
- In the second phase, except for one farm site, no statistically significant differences in soil P were observed at planting or harvesting (Table 12).

4. Was P tissue accumulation different among rates? Were P tissue levels at adequate concentrations even at low application rates?

Based on three representative tomato farms for which biomass and P tissue concentration for the leaf, stem, and fruit parts of the plant were available, the average P tissue accumulation during the life of the crop was comparable at rates ranging from 60 to 120 P_2O_5 pounds per acre (Table 13). However, accumulation levels varied from farm to farm and during the life of the crop.

Figures 2 and 3 present the P accumulation levels for the two spring and the one fall demonstrations, respectively.

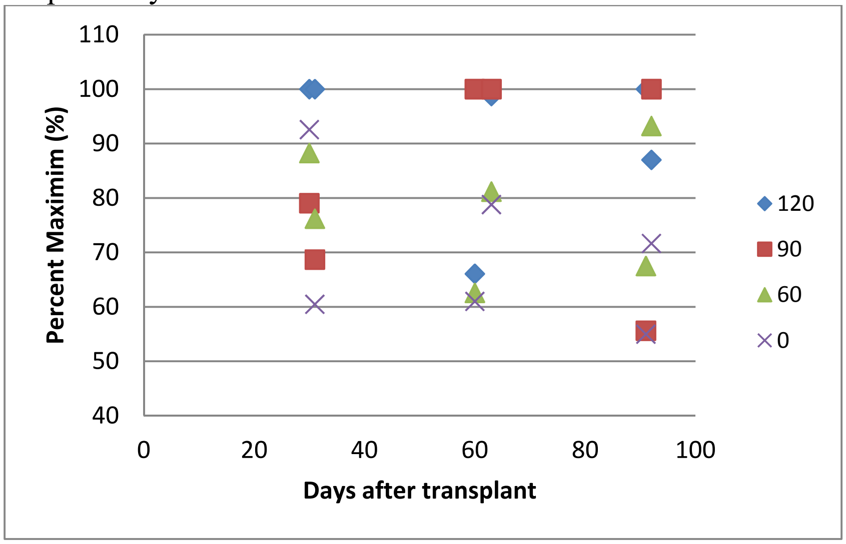

Figure 2. Percent maximum P accumulation at P rates using uncoated fertilizer for Spring Tomato Demonstrations.

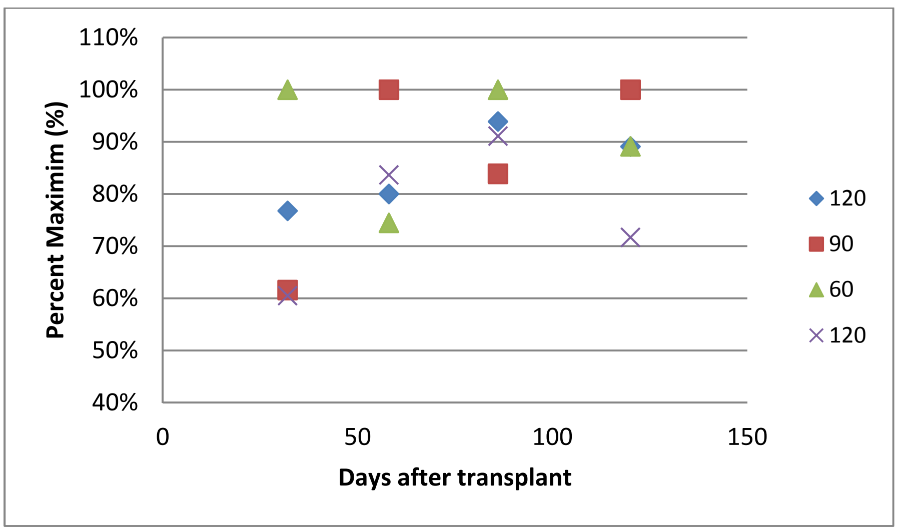

Figure 3. Percent maximum P accumulation at P rates using uncoated fertilizer for the Fall Tomato Demonstration.

Total above ground P accumulation (sum of leaf, stem and fruit P content) increased with DAT (Table 13). With one exception early in the season (Farm 3A Spring 2011, 43 DAT), maximum P accumulation (100% relative accumulation) was at rates of 60 pounds P_2O_5 per acre or greater. After 30 DAT, average tissue P accumulation was similar for all P rates of 60 pounds P_2O_5 per acre or greater except early in the growing season. In addition, leaf P concentrations met the sufficiency levels for the tomato demonstrations (0.2 to 0.4 mg kg^{-1}, as indicated earlier in Table 2). However, differences in leaf P levels were observed from farm to farm: while approximately 70% of the leaf P measurements for Farm 2 exceeded the upper sufficiency threshold of 0.4 mg kg^{-1}, only 25% exceeded this threshold for Farm 3A (Appendix A).

Table 9. First Phase - Soluble P Rates Resulting in Significantly Highest Levels of Tomato Yield, Biomass and Soil P in Field Studies.

Demonstration Site	Farm 1	Farm 1	Farm 1	Farm 3A	Farm 3A	Farm 4	Average P rate across sites for First Phase			
Year	2006	2006	2007	2006	2007	2007				
Season	Spring	Fall	Fall	Spring	Spring	Spring	Criteria I: All sites and seasons		Criteria II: Excludes sites with substantial weather effects	
Substantial affected by Weather Effects?	No	No	No	No	No	No				
Parameter Measured	P rates (P_2O_5 pounds/acre)						Mean	Rounded to Test Rate	Mean	Rounded to Test Rate
First extra-large yield	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Total extra-large yield	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Total yield	0	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Total biomass	NA[2]	NS[1]	0	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Leaf P	50	NS[1]	NS[1]	NS[1]	NS[1]	NA[2]	NS[1]	NS[1]	NS[1]	NS[1]
Fruit biomass	NA[2]	0	0	NA[2]	50	NA[2]	17	50	17	50
Soil P at planting	NS[1]	NS[1]	NS[1]	50	100	NS[1]	75	84	75	84
Soil P at harvest	NS[1]	84	NS[1]	NS[1]	50	112	82	84	82	84

[1]NS: No statistical significance among the rates therefore these data were not used in the calculation of means for Criteria I or II in Table 10.
[2]NA: Not available.
[3]Only one harvest, thus the rate for the total extra-large yield is used.

Table 10. Second Phase - Soluble P Rates Resulting in Significantly Highest Levels of Tomato Yield, Biomass and Soil P in Field Studies.

Demonstration Site	Farm 1	Farm 1[1]	Farm 1[1]	Farm 2	Farm 2	Farm 2	Farm 3A[1]	Farm 3A	Farm 6B	Farm 6A	Average P rate across sites for Second Phase			
Year	2008	2009	2010	2010	2009	2011	2008	2011	2009	2009	Criteria I: All sites and seasons		Criteria II: Excludes sites with substantial weather effects	
Season	Fall	Fall	Fall	Fall	Spring	Spring	Fall	Spring	Fall	Fall				
Substantial affected by Weather Effects?	No	Yes	Yes	No	No	No	Yes	No	No	No				
Parameter Measured	P rates (P_2O_5 pounds/acre)										Mean	Rounded to Test Rate	Mean	Rounded to Test Rate
First extra-large yield	0	0[4]	60	NS[2]	60	90	120[4]	0	NS[2]	NS[2]	47	60	38	60
Total extra-large yield	0	0	60	0	60	60	120	120	NS[2]	NS[2]	53	60	48	60
Total yield	0	60	0	90	90	120	NS[2]	NS[2]	NS[2]	60	60	60	72	90
Total biomass	NS[2]	0	0	90	0	90	NS[2]	0	90	NS[2]	39	60	54	60
Leaf biomass	NA[3]	NA[3]	0	90	NA[3]	60	NA[3]	120	NA[3]	NA[3]	68	90	90	90
Leaf P	90	90	120	60	NS[2]	90	NS[2]	60	NS[2]	NS[2]	85	90	75	90
Stem biomass	NA[3]	NA[3]	60	NS[2]	NA[3]	0	NA[3]	NS[2]	NA[3]	NA[3]	30	60	NS[2]	NS[2]
Fruit biomass	120	60	NS[2]	0	0	NS[2]	NS[2]	0	NS[2]	0	30	60	24	60
Soil P prior to planting	60	0	60	0	90	60	NS[2]	NS[2]	NS[2]	NS[2]	45	60	53	60
Soil P at harvest	NS[2]	90	90	NS[1]	90	120	90	90	NS[2]	120	99	120	105	120

[1] Substantial weather effects.
[2]NS: No statistical significance among the rates therefore these data were not used in the calculation of means for Criteria I or II.
[3]NA: Not available.
[4]Only one harvest, thus the rate for the total extra-large yield is used.

Table 11: First Phase: Soluble P Rates Resulting in Significantly Highest Levels of Green Bean Yield, Biomass and Soil P in Field Studies.

Demonstration Site	Farm 2	Farm 2	Farm 3A[1]	Farm 3A	Farm 3A	Farm 3B	Farm 3B[1]	Farm 3B	Farm 3B	Farm 3B	Average P rate across sites for First Phase			
Year	2006	2007	2006	2007	2008	2006	2006	2007	2007	2008				
Season	Fall	Fall	Fall	Fall	Spring	Spring	Fall	Spring	Fall	Spring	Criteria I: All sites and seasons		Criteria II: Excludes sites with questionable data	
Substantial affected by Weather Effects?	No	No	No	No	No	No	No	No	No	No				
Parameter Measured	P rates (P_2O_5 pounds/acre)										Mean	Rounded to Test Rate	Mean	Rounded to Test Rate
Total large yield	NS[2]	30	NS[2]	NS[2]	50	NS[2]	40	40	50	50	43	50	43	50
Total yield	NS[2]	30	NS[2]	NS[2]	25	NS[2]	NS[2]	NS[2]	50	NS[2]	35	40	35	40
Total biomass	NS[2]	NS[2]	0	25	25	39	NS[2]	40	50	50	33	40	33	40
Plant stand	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]
Leaf P	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	50	NS[2]	NS[2]	NS[2]	NS[2]
Soil P at planting	0	NS[2]	40	NS[2]	50	NS[2]	NS[2]	40	NS[2]	50	36	40	36	40
Soil P at harvest	NS[2]	NS[2]	NS[2]	25	NS	NS[2]	40	0	NS	50	29	40	29	40

[1]Questionable data.
[2]NS: No statistical significance among the rates, therefore these data were not used in the calculation of means for Criteria I or II.

Table 12. Second Phase – Soluble P Rates Resulting in Significantly Highest Levels of Green Bean Yield, Biomass and Soil P in Field Studies.

Demonstration Site	Farm 2	Farm 3A	Farm 2[1]	Farm 2	Farm 3A[1]	Farm 3B	Average P rate across sites for Second Phase			
Year	2008	2009	2009	2010	2010	2010	Criteria I: All sites and seasons		Criteria II: Excludes sites with substantial weather effects	
Season	Fall	Spring	Fall	Spring	Spring	Spring				
Substantial affected by Weather Effects?	No	No	Yes	No	Yes	No				
Parameter Measured							Mean	Rounded to Test Rate	Mean	Rounded to Test Rate
Total large yield	60	NS[2]	NS[2]	40	0	NS[2]	33	40	50	60
Total yield	60	NS[2]	NS[2]	40	NS[2]	NS[2]	50	60	50	60
Total or plant biomass	NS[2]	NS[2]	40	0	NS[2]	NS[2]	20	40	NS[2]	NS[2]
Plant stand	NS[2]	NS[2]	NS[2]	0	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]
Leaf P	0	NS[2]	NS[2]	40	NS[2]	NS[2]	20	40	20	40
Soil P at planting	NS[2]	NS[2]	NS[2]	NS[2]	40	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]
Soil P at harvest	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]

[1]Substantial weather effects.
[2]NS: No statistical significance among the rates, therefore these data were not used in the calculation of means for Criteria I or II.
[3]NA: Not applicable as statistically significant data for more than one demonstration are not available.

Table 13.Table 13. P Tissue Accumulation for Tomatoes.

Demonstration	Farm 2 Fall 2010							
Parameter	P Tissue Accumulation (g)				P Tissue Accumulation (%)			
DAT/Rate	120	90	60	0	120	90	60	0
32	0.40	0.32	0.53	0.32	77%	62%	100%	61%
58	2.37	2.97	2.21	2.48	80%	100%	74%	84%
86	3.02	2.69	3.21	2.93	94%	84%	100%	91%
120	5.08	5.71	5.09	4.09	89%	100%	89%	72%
Demonstration	Farm 2 Spring 2011							
Parameter	P Tissue Accumulation (g)				P Tissue Accumulation (%)			
DAT/Rate	120	90	60	0	120	90	60	0
31	0.55	0.38	0.42	0.33	100%	69%	76%	60%
63	3.85	3.90	3.17	3.07	99%	100%	81%	79%
92	5.31	6.11	5.69	4.38	87%	100%	93%	72%
Demonstration	Farm 3A Spring 2011							
Parameter	P Tissue Accumulation (g)				P Tissue Accumulation (%)			
DAT/Rate	120	90	60	0	120	90	60	0
31	0.41	0.46	0.41	0.90	46%	51%	46%	100%
63	3.36	4.94	3.30	0.68	68%	100%	67%	14%
92	6.41	3.67	6.01	1.00	100%	57%	94%	16%

Demonstration	Summary			
Parameter	P Tissue Accumulation (%)			
DAT/Rate	120	90	60	0
31	74%	60%	74%	74%
61	82%	100%	74%	59%
90	94%	80%	96%	59%
120	89%	100%	89%	72%
Average P Tissue Accumulation	85%	85%	83%	66%

3.2 Demonstration of Coated Fertilizers

Out of the 18 sites evaluated during the 2008 – 2011 growing seasons, five (5) tomato and one (1) green bean site demonstrated the effect of sulfur and polymer coated fertilizers in comparison to soluble (uncoated) fertilizers. As in previous sections, questions were developed to summarize the findings. Please note when reviewing the results that nitrogen and potassium components are also coated (besides P). For example, any differences between the effects of no P_2O_5 uncoated fertilizer and no P_2O_5 coated fertilizer may be due to the coating of nitrogen and potassium. Please refer to tables 14 - 19 for individual results for tomatoes and green beans respectively. Questions and answers are indicated next:

*1. **Did total or total extra-large yield increase when coated fertilizers were used**?*

Data were reviewed to determine if coated fertilizers resulted in statistically similar highest yields as uncoated fertilizers, or if coated fertilizers at lower application rates could result in statistically similar highest yields than uncoated fertilizers.

Tomato: Three (3) participating farms including five (5) demonstrations were evaluated. Two of the sites were substantially affected by weather and results were not representative. As a result findings could only be developed based on two (2) demonstrations in Farm 2 and one (1) demonstration in Farm 3A, as follows:

- Except for total yield for Farm 3A, statistically similar highest yields were obtained at different combinations of application rate and coating materials. For example, statistically similar highest yields were obtained with either 90 P_2O_5 pound per acre using soluble (uncoated) fertilizer, 90 P_2O_5 pound per acre sulfur coated fertilizer and with no P_2O_5 polymer coated fertilizer for the Fall 2010 Farm 2 demonstration (Table 14).
- The combinations resulting in the highest yields varied from demonstration to demonstration and parameter to parameter. For example, while the highest total yield for the Fall 2010 Farm 2 demonstration was obtained with no P_2O_5 polymer coated fertilizer, the highest total extra-large fruit yield was obtained with 90 P_2O_5 pound per acre polymer coated fertilizer rate.
- For the exception in Farm 3A, the statistically highest total yield was obtained with uncoated fertilizer. Sulfur and polymer coated materials, even at alternate rates, did not achieve total yields that were statistically similar to the highest yields using uncoated fertilizer.
- Please refer to shaded cells in Table 14 indicating the coated fertilizer rates in comparison to the uncoated fertilizer rates. These preliminary data may suggest a potential benefit from polymer coated fertilizer. However, given the limited data and contrasting results, follow-up evaluations are needed for conclusive results. The demonstrations in this project tested fertilizers that were either 100% soluble or 100% coated materials, perhaps evaluating whether a combination of coated and non-coated fertilizer would produce highest yields that a single material could be considered.

Green bean: For the single green bean demonstration where coated fertilizers were evaluated, statistically similar yields were obtained with sulfur coated fertilizers with zero P and with soluble fertilizers at a 40 P_2O_5 pound per acre rate. Results are presented in Table 15. Follow-up evaluations are needed to verify these promising results.

2. Were there leaf, stem or fruit biomass differences among coatings?

As with yield, data were reviewed to determine if coated fertilizers resulted in higher total biomass, leaf biomass, stem biomass, and fruit biomass than those obtained with uncoated fertilizers, and if coated fertilizers could produce highest biomass levels at lower application rates. Findings per crop are presented next:

Tomato:

- Results in Farm 2 and Farm 3A suggested different responses on biomass from the application of coated fertilizers from farm to farm.
- Different combinations of application rate and coating materials produced statistically similar highest biomass levels, except for stem biomass with sulfur coated fertilizer at Farm 3A. For Farm 3A, sulfur coated fertilizers resulted in significantly lower stem biomass than uncoated and polymer coated fertilizers. In contrast, the findings on stem biomass for Farm 2 indicated no statistically significant differences for one demonstration and highest stem biomass with no P_2O_5 application for the other, regardless of the coating.
- For leaf biomass, coated fertilizers produced statistically similar high leaf biomass at lower rates than uncoated fertilizers.
- The application of no P_2O_5 resulted in the highest fruit biomass regardless of the coating in the single demonstration in Farm 3A and in one of the demonstrations in Farm 2 (the other was not statistically significant).
- For total biomass, which encompasses the individual results above, differences between Farm 2 and Farm 3A responses were apparent. For Farm 2, the lowest P rate resulting in statistically highest total biomass with soluble fertilizer was 90 pounds P_2O_5 per acre, while no P_2O_5 application was needed with polymer coated fertilizers based on the two demonstrations conducted, indicating reduced fertilizer requirements to grow similar size plants. For Farm 3A, highest amounts of P_2O_5 were required with coated fertilizers than with soluble fertilizer based on the single demonstration conducted.

Green bean: Only one green bean crop was grown with sulfur coated fertilizers and none were grown with polymer coated fertilizer. Plant biomass and plant stand were both statistically highest with no P applied when sulfur coated fertilizers were used. In addition, significantly similar levels of leaf P accumulation were observed with no P sulfur coated fertilizers and with uncoated fertilizers at the 40 P_2O_5 pound per acre rate. Results are presented in Table 15. Follow-up evaluations are needed to verify these promising results.

3. Was P tissue accumulation different among coatings?

Nutrients accumulate in plant tissue at different rates and concentrations based on different conditions such as nutrient availability to the plant. In order to review the effects of coating materials on nutrient availability, P tissue concentration at harvest and P tissue accumulation during the life of the crop were compared among coated and uncoated fertilizers.

Tomato: At harvest, statistically similar highest levels of P in leaf and fruit tissue were observed with different combinations of coating and P rate, as indicated in Table 14. The highest leaf P levels were observed with lower rates of coated fertilizers (zero P_2O_5 rate) than uncoated fertilizers in one of the two coating treatments for each demonstration. However, the fact that the application rate was the zero rate, poses questions on the results (no P_2O_5 was provided that could have been made more available due to the coating). For fruit P, highest P tissue levels were observed at lower rates of coated fertilizers for the single demonstration at Farm 3A. For stem P, differences between the treatments were not statistically significant in two of the three demonstrations.

Total plant P accumulation (leaves, stems and fruit) was also estimated for samples taken at approximately 30 day intervals and compared among coated and uncoated fertilizers at similar rates for each demonstration (Tables 16 to 15). P accumulation varied for the different demonstrations, rates, and dates. However, on average, P accumulation for uncoated fertilizers was very similar to coated fertilizers.

Regarding P accumulation for different rates of coated fertilizers, data suggests, but does not conclusively prove, that maximum P accumulation is provided by the 120 and 90 pound per acre P rates of sulfur coated fertilizer materials. The results also suggest that P accumulation for the 60 pound P rate of sulfur coated materials was similar to the zero P rate for the spring tomato crops (Figure 4). The same trends are not as clear when percent maximum total plant P accumulation using polymer coated materials are analyzed graphically (Figure 6). Total P accumulation for the highest P rates of polymer coated fertilizer was similar to the zero P application rate, suggesting a reduction in rate of release of P from the polymer coated materials so that lower P was available to the plant.

For the Fall tomato crops (Figure 5), P accumulation started out above 80% thirty days after transplant for the lower P rates and essentially 100% for the higher P rates. Over the life of the crop, P accumulation with the higher P rates tended to decline while the lowest P rate stayed relatively constant and the second lowest increased until 90 days after transplant and then declined to approximately the same level (85%) as the other P rates. This would indicate that the coated sulfur had an immediate but short term affect in making more P available with less of an effect on the lower P rates but by 60 days after transplant, the affect began to diminish. For polymer coated fertilizers (Figure 7), there is no discernible effect or trend in P accumulation among the different P rates.

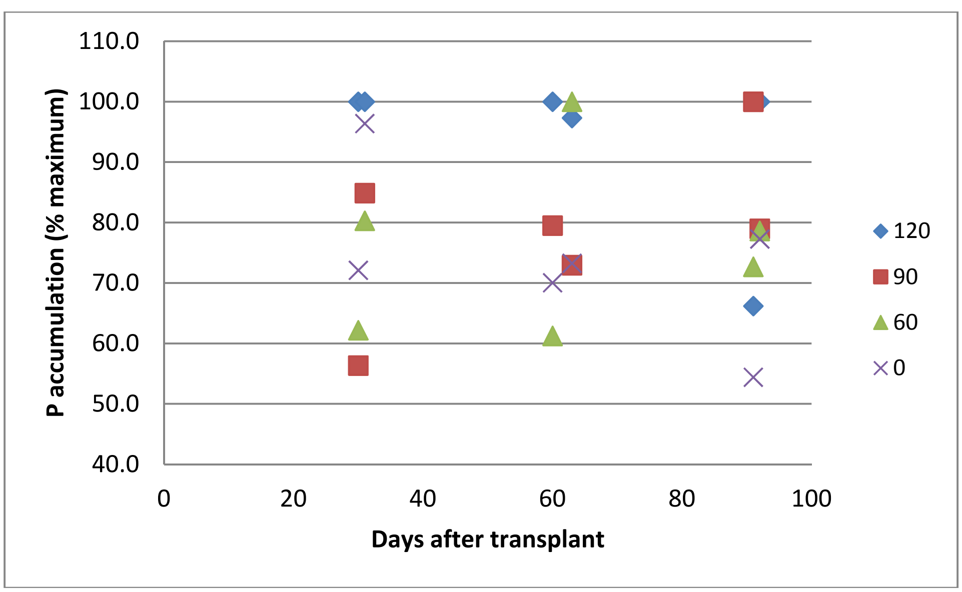

Figure 4. Percent Maximum P Accumulation for Spring Tomato Demonstration at Varied Rates of Sulfur Coated Fertilizer.

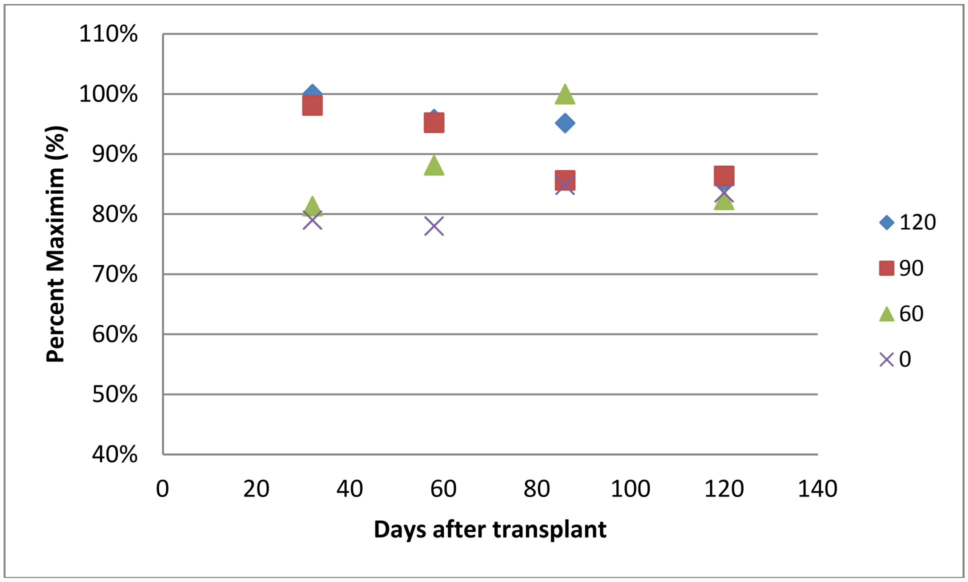

Figure 5. Percent Maximum P Accumulation for the Fall Tomato Demonstration at Varied Rates of Sulfur Coated Fertilizer.

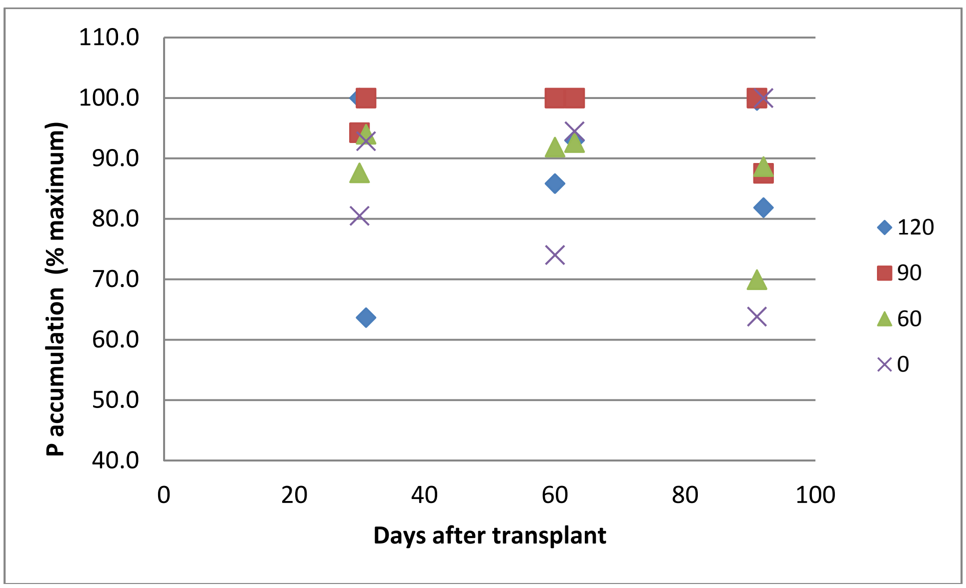

Figure 6. Percent Maximum P Accumulation for the Spring Demonstrations at Varied Rates of Polymer Coated Fertilizer.

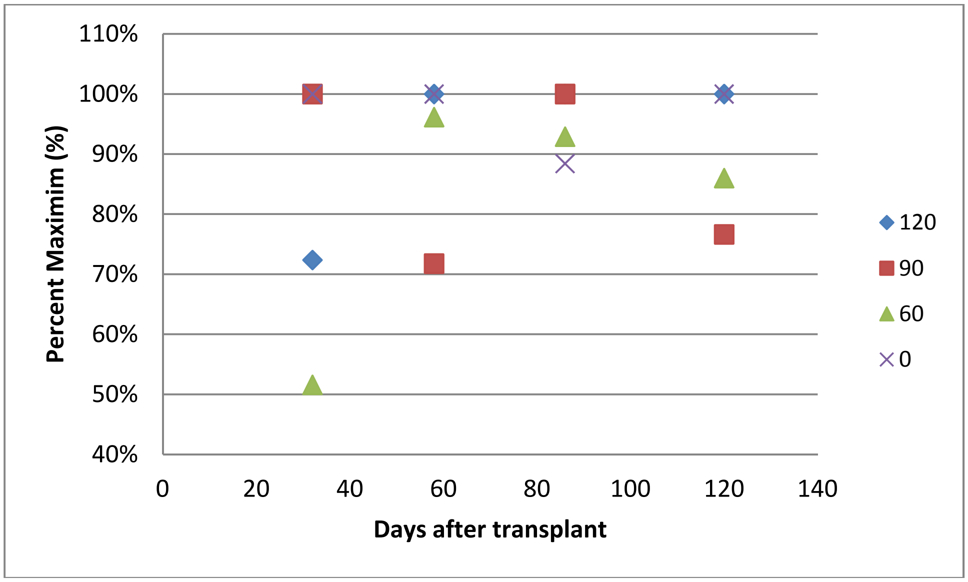

Figure 7. Percent Maximum P Accumulation for the Fall Demonstration at Varied Rates of Polymer Coated Fertilizer.

While combinations of application rate and coating treatments resulted in different P accumulation rates during the life of the crop, data were also reviewed to determine the P accumulation rates for the treatments resulting in the statistically similar highest biomass, as presented in figures 8 to 10. The biomass accumulation ranged from approximately 3 to 6 grams of P per plant at harvest with the highest ranges observed at the highest application rates of each coating treatment.

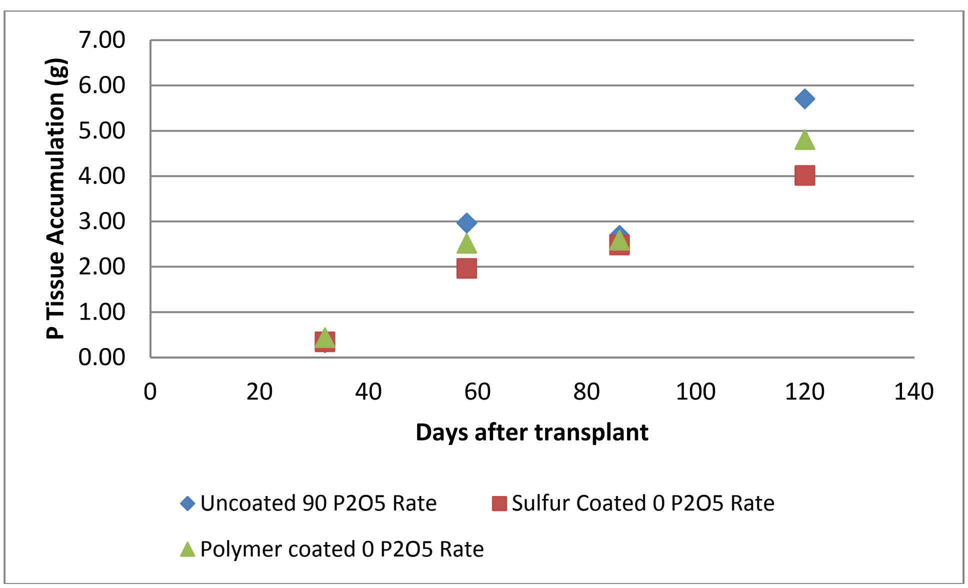

Figure 8. P accumulation at a Combination of P Rates and Coating Treatments Resulting in the Statistically Similar Higher Biomass for Farm 2 in the Fall of 2010.

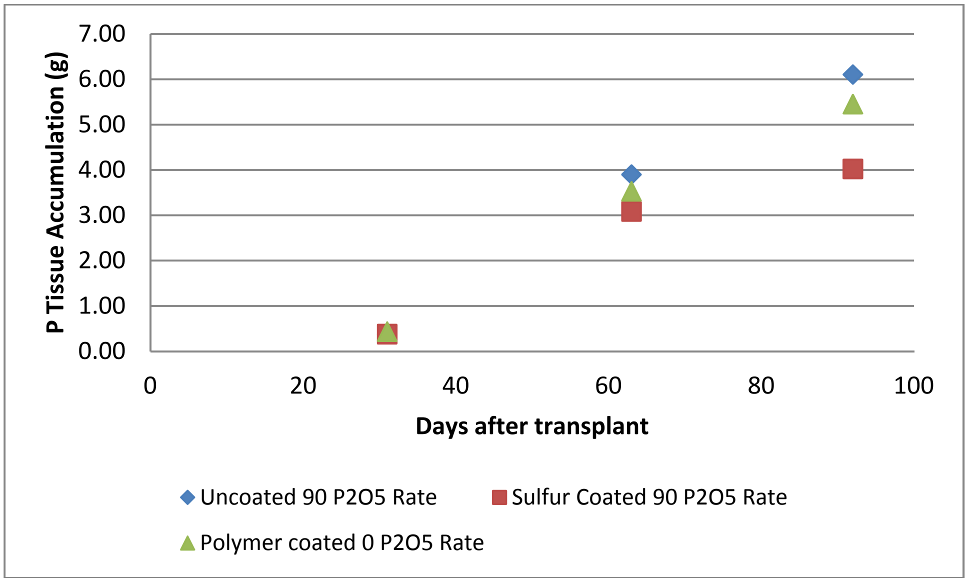

Figure 9. P accumulation at a Combination of P Rates and Coating Treatments Resulting in the Statistically Similar Higher Biomass for Farm 2 in the Spring of 2011.

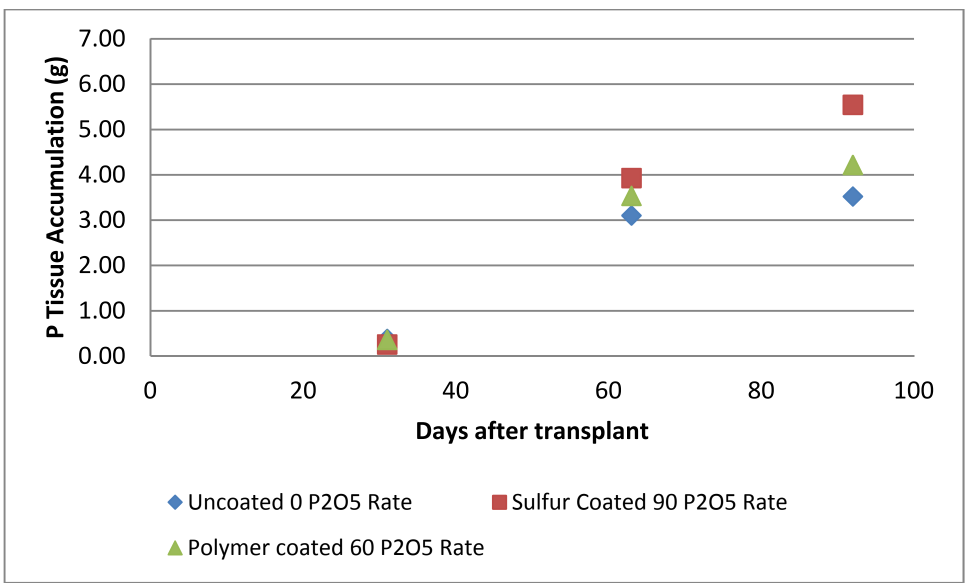

Figure 10. P accumulation at a Combination of P Rates and Coating Treatments Resulting in the Statistically Similar Higher Biomass for Farm 3A in the Spring of 2011.

4. Did coatings affect soil P at harvest?

Tomato: Results were inconclusive. For the fall representative site, there were no statistically significant differences among the coating treatments at harvest despite significantly highest levels at planting. The two spring sites offered contrasting results:

- In Farm 2, soil P levels at planting indicated that the plot to receive the 60 pounds of P_2O_5 per acre application rate and the plots receiving the zero rate of P_2O_5 coated fertilizers had statistically significant highest soil P. At harvest, the zero rate of P_2O_5 coated fertilizer plots continued to be at the same highest levels, however, the plot receiving the 120 P_2O_5 uncoated fertilizer rate became the statistically highest soil P plot.
- In Farm 3A, statistically similar highest soil P levels at harvest were obtained when applying uncoated fertilizers at 90 pounds per acre of P_2O_5 and sulfur and polymer coated fertilizers at 120 and 60 pounds per acre respectively. There were not statistically significant differences in the plots at planting.

Green beans: There were no statistically significant differences between soil P for coated and uncoated fertilizers.

5. ***Did water soluble ortho phosphorus or total P vary with increase with P rate or coated materials?***

Concurrent with the demonstration projects, water quality monitoring was conducted to determine the effect of P_2O_5 application rates and coating materials on the P that is transported from the fields to the ditches and farm canals during storm and irrigation events. Between five and nine grab samples were collected for each site during the life of the crop. Two demonstrations were for tomatoes and one for green beans. Please refer to Table 19 indicating the lowest application rates or coating type resulting in statistically highest Total P or Ortho P in comparison to the other treatments.

- Regarding the effect of P_2O_5 application rates, statistically significant increases in water Ortho P levels were found only for green beans. Specifically, highest concentrations were measured for the blocks receiving as low as 40 pounds per acre of P_2O_5 in two of the three samples collected after planting. There were no statistical differences in Ortho P levels for this site prior to planting.

- Regarding the effect of coating materials, the two tomato sites reported a single instance where Total P or Ortho P was statistically highest when sulfur or polymer coatings were used. There were no statistically significant differences in Total or Ortho P levels for these sites prior to planting. For the green bean site, the pre-plant ditch water indicated significantly highest Ortho P levels for the uncoated and the polymer coated blocks. However, these significant differences did not persist during the life of the crop based on the samples collected.

While there was limited collection of water quality data during the demonstration, it would appear that P_2O_5 application rates may have a statistically significant impact on Ortho P levels on individual discharge events during the life of the crop. However, as the crop is mostly grown during the dry season, the effects of any residual soil P on wet season discharges were not captured by the experiment design. Expanding water quality collection during the subsequent wet season and relating this information to soil P levels would have provided a more comprehensive overview of the effects of the different treatments on water quality.

Table 14. Effect of coatings and treatment rates on tomato yield, biomass and soil P.

Demonstration Site	Farm 1		Farm 1			Farm 2			Farm 2			Farm 3A			Average all sites rounded to test rate			Average excluding site with substantial weather effects rounded to test rate		
Year	2009		2010			2010			2011			2011								
Season	Fall		Fall			Fall			Spring			Spring								
Substantially affected by Weather?	Yes		Yes			No			No			No								
Treatment	Uncoated (Soluble)	Sulfur Coated	Uncoated (Soluble)	Sulfur Coated	Polymer Coated	Uncoated (Soluble)	Sulfur Coated	Polymer Coated	Uncoated (Soluble)	Sulfur Coated	Polymer Coated	Uncoated (Soluble)	Sulfur Coated	Polymer Coated	Uncoated (Soluble)	Sulfur Coated	Polymer Coated	Uncoated (Soluble)	Sulfur Coated	Polymer Coated
Parameter	Lowest P rates (P_2O_5 pounds/acre) Resulting in Statistically Highest Level																			
First extra-large yield	0[1]	0[1]	60[1]	0[1]	0[1]	NS[2]	NS[2]	NS[2]	90	0	60	0	60	60	60	60	60	60	60	60
Total extra-large yield	0	0	60	0	0	0	90	90	60	90	120	120	120	60	60	60	90	60	120	90
Total yield	60	0	0	60	0	90	90	0	120	120	0	NS[3]	NS[3]	NS[3]	90	90	0	120	120	0
Total biomass	0	0	0	60	60	90	0	0	90	90	0	0	90	60	60	60	60	60	60	60
Leaf biomass	NA[4]	NA[4]	0	60	0	90	0	0	60	90	0	120	90	120	90	60	60	90	60	60
Leaf P	90	0	120	0	60	60	120	0	90	120	0	60	0	60	90	60	60	90	90	60
Stem biomass	NA[4]	NA[4]	60	120	120	NS[2]	NS[2]	NS[2]	0	0	0	NS[5]	NS[5]	NS[5]	60	60	60	NS[2]	NS[2]	NS[2]
Stem P	NA[4]	NA[4]	0	0	0	0	60	0	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	NS[2]	0	60	0	NS[2]	NS[2]	NS[2]
Fruit biomass	60	60	NS[2]	NS[2]	NS[2]	0	0	0	NS[2]	NS[2]	NS[2]	0	0	0	60	60	0	0	0	0
Fruit P	NA[4]	NA[4]	120	0	90	60	120	120	NS[2]	NS[2]	NS[2]	120	90	90	120	90	120	90	120	120
Soil P at planting	0	0	60	0	60	0	90	60	60	0	0	NS[2]	NS[2]	NS[2]	60	60	60	60	60	60
Soil P at harvest	90	120	90	90	0	NS[2]	NS[2]	NS[2]	120	0	0	90	120	60	120	90	60	120	60	60

Notes: Shaded cells indicate lower rates of coated fertilizers result in statistically similar levels to those obtained with highest rates of uncoated fertilizers

[1] Only one harvest was collected, therefore, the total extra large yield is the same as the first extra large yield and was used for calculations. [2]NS: Not statistically significant differences across coating treatments *and/or* rates (combined or individually). [3]No statistical differences for coating treatment *and* rate combinations were found. However, statistical differences were found for coating treatment and rate individually. The lowest P rate resulting in statistically highest total yield was 90 pounds/acre across coating treatments. The coating that provided the statistically highest total yield was "Uncoated" with an average yield across all p-rates of 1742 boxes/acre. [4]NA: Not available, as data were not collected. [5]No statistical differences for coating treatment and rate combinations were found. However, statistical differences were found for coating treatment and rate individually. The lowest P rate resulting in statistically highest stem biomass was 0 pounds/acre across coating treatments (no effect). The coatings that provided the statistically highest stem biomass were "Uncoated" and "Polymer" each with an average biomass of 278 grams/plant.

Table 15. Effect of coatings and treatment rates on green bean yield, biomass and soil P.

Demonstration Site	Farm 2	
Year	2010	
Season	Spring	
Substantial affected by weather?	No	
Treatment	Uncoated (Soluble)	Sulfur Coated
Parameter Measured	P rates (P_2O_5 pounds/acre)	
First large yield (4-6 inch)	40[1]	0[1]
Total large yield (4-6 inch)	40	0
Total yield	40	0
Plant biomass	0	0
Plant stand (#/ 10 feet)	0	0
Leaf P	40	0
Soil P at planting	NS[2]	NS[2]
Soil P at harvest	NS[2]	NS[2]

Notes:
[1]Only one harvest was collected, therefore, the total extra large yield is the same as the first extra large yield and was used for calculations.
[2]Not statistically significant.

Table 16. P Tissue Accumulation at Different Coating Rates Farm 2 Fall 2010

Rate	120 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
32	0.40	0.43	0.31	94%	100%	72%
58	2.37	2.72	2.84	84%	96%	100%
86	3.02	2.94	3.09	98%	95%	100%
120	5.08	5.27	6.17	82%	85%	100%
Rate	90 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
32	0.32	0.42	0.43	76%	98%	100%
58	2.97	2.83	2.13	100%	95%	72%
86	2.69	2.80	3.27	82%	86%	100%
120	5.71	4.93	4.37	100%	86%	77%
Rate	60 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
32	0.53	0.43	0.27	100%	81%	52%
58	2.21	1.95	2.12	100%	88%	96%
86	3.21	3.33	3.09	97%	100%	93%
120	5.09	4.19	4.37	100%	82%	86%
Rate	0 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
32	0.32	0.35	0.44	73%	79%	100%
58	2.48	1.96	2.52	99%	78%	100%
86	2.93	2.48	2.59	100%	85%	88%
120	4.09	4.02	4.81	85%	84%	100%

Summary					
Rate	Uncoated	Sulfur Coated	Polymer Coated	Difference with Sulfur Coated	Difference with Polymer Coated
120	90%	94%	93%	5%	4%
90	90%	91%	87%	2%	-2%
60	99%	88%	82%	-11%	-17%
0	89%	81%	97%	-8%	8%
Average	92%	89%	90%	-3%	-2%

Table 17. P Tissue Accumulation at Different Coating Rates Farm 2 Spring 2011

Rate	120 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.55	0.45	0.30	100%	81%	54%
63	3.85	4.12	3.47	94%	100%	84%
92	5.31	5.09	4.46	100%	96%	84%
Rate	90 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.38	0.38	0.47	81%	81%	100%
63	3.90	3.09	3.73	100%	79%	96%
92	6.11	4.02	4.77	100%	66%	78%
Rate	60 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.42	0.36	0.44	96%	81%	100%
63	3.17	4.23	3.46	75%	100%	82%
92	5.69	4.01	4.84	100%	70%	85%
Rate	0 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.33	0.43	0.44	77%	99%	100%
63	3.07	3.10	3.53	87%	88%	100%
92	4.38	3.94	5.45	80%	72%	100%

Summary					
Rate	Uncoated	Sulfur Coated	Polymer Coated	Difference with Sulfur Coated	Difference with Polymer Coated
120	98%	92%	74%	-6%	-24%
90	94%	75%	91%	-18%	-2%
60	90%	84%	89%	-6%	-1%
0	81%	86%	100%	5%	19%
Average	91%	84%	89%	-6%	-2%

Table 18. P Tissue Accumulation at Different Coating Rates Farm 3A Spring 2011

Rate	120 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.41	0.46	0.41	90%	100%	90%
63	3.36	4.94	3.30	68%	100%	67%
92	6.41	3.67	6.01	100%	57%	94%
Rate	90 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.32	0.26	0.39	84%	66%	100%
63	5.08	3.93	3.85	100%	77%	76%
92	3.56	5.55	6.03	59%	92%	100%
Rate	60 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.36	0.28	0.36	100%	79%	100%
63	3.18	3.03	3.54	90%	86%	100%
92	4.33	4.03	4.22	100%	93%	98%
Rate	0 pounds/acre P_2O_5					
Parameter	P Tissue Accumulation (g)			P Tissue Accumulation (%)		
DAT\Coating	Uncoated	Sulfur Coated	Polymer Coated	Uncoated	Sulfur Coated	Polymer Coated
31	0.38	0.33	0.33	100%	87%	87%
63	3.10	3.46	2.85	90%	100%	82%
92	3.52	3.02	3.85	92%	78%	100%

Summary					
Rate	Uncoated	Sulfur Coated	Polymer Coated	Difference with Sulfur Coated	Difference with Polymer Coated
120	86%	86%	84%	0%	-2%
90	81%	79%	92%	-2%	11%
60	97%	86%	99%	-11%	2%
0	94%	88%	90%	-5%	-4%
Average	89%	85%	91%	-5%	2%

Table 19. Effect of coating and treatment rates on water quality.

Demonstration Site		Farm 2	Farm 2	Farm 2	Farm 2	Farm 2	Farm 2
Year		2010	2010	2011	2010	2010	2011
Season		Spring	Fall	Spring	Spring	Fall	Spring
Crop		Green beans	Tomato	Tomato	Green beans	Tomato	Tomato
Substantial affected by Weather Effects?		No	No	No	No	No	No
Parameter Measured	Sample number	Effects by P rates (P_2O_5 pounds/acre)			Effect by Coating Type		
Total P	Pre-plant	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	Pre-plant	NS[1]	NS[1]	NS[1]	None + Polymer	NS[1]	NS[1]
Total P	2	NS[1]	NS[1]	NS[1]	NS[1]	Sulfur + Polymer	NS[1]
Ortho-P	2	40	NS[1]	NS[1]	NS[1]	NS[1]	None
Total P	3	NS[1]	NS[1]	NS[1]	NS[1]	NS[1,2]	NS[1]
Ortho-P	3	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	Sulfur + Polymer
Total P	4	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	4	40	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Total P	5		NS[1]	NS[1]		NS[1]	NS[1]
Ortho-P	5		NS[1]	NS[1]		NS[1]	NS
Total P	6			NS[1]			NS[1]
Ortho-P	6			NS[1]			NS[1]
Total P	7			NS[1]			NS[1]
Ortho-P	7			60			NS[1]
Total P	8			NS[1]			NS[1]
Ortho-P	8			NS[1]			NS[1]

[1]NS: No statistical significance among the rates

Shaded cells indicate the lowest P_2O_5 application rates or coating treatments resulting in statistically highest Total P or Ortho P.

3.3 Greenhouse Lysimeter Studies

Two lysimeter studies were conducted in the Spring of 2011 and the Fall of 2011 at greenhouses located at the University of Florida, Southwest Florida Research and Education Center near Immokalee, FL. The objective of the studies was to determine the effect of two P application methods on tomato yield, growth, and water quality. The two application methods were 1) the application of P through weekly injections in a drip irrigation system (fertigation), and 2) the application of P by weekly foliar sprays. The P rates were the same used in the field demonstration project (0, 60, 90, and 120 pounds P_2O_5 per acre per season).

Results indicate that yields for both greenhouse studies responded positively to increase in P application rate with highest total extra-large yield and total yield at 90 pounds per acre per season with fertigation, and at 60 pounds per acre for foliar application method for the spring study (Table 20). The highest significant yield of extra-large fruit at first harvest was similar to total extra-large and total yields at 120 pounds P_2O_5 per acre in the fall study. Leaf and stem biomass at the end of the season indicated that sufficient P was provided by the lowest P rates but 60 or more pounds P_2O_5 per acre were associated with the highest significant leaf and stem tissue P concentrations. Water quality samples at the end of the season indicated no significant difference in total P leachate by P rate, application method or interaction of the P rate and method. However, mixed results were found for Ortho P.

Table 20. Summary of lowest P rates for tomato greenhouse lysimeter studies resulting in significantly highest plant response.

Parameter	Treatment[1]	Greenhouse Lysimeters, Spring 2011	Greenhouse Lysimeters, Fall 2011
		P_2O_5 Rate (pounds per acre)[2]	
First extra-large yield	Foliar	60	NS[3]
	Fertigation	60	NS[3]
	Rate	120	120
Total extra-large yield	Foliar	60	NS[3]
	Fertigation	90	NS[3]
	Rate	120	120
Total yield	Foliar	60	NS[3]
	Fertigation	90	NS[3]
	Rate	120	120
Leaf biomass at harvest	Foliar	NS	NS[3]
	Fertigation	NS	NS[3]
	Rate	60	60
Stem biomass at harvest	Foliar	60[3]	NS[3]
	Fertigation	60[3]	NS[3]
	Rate	60	60
Root biomass at harvest	Foliar	NS	NS
	Fertigation	NS	NS
Leachate total P at harvest	Foliar	NS	NS
	Fertigation	NS	NS
Leachate Ortho P at harvest	Foliar	0	90
	Fertigation	0	0

[1]Phosphorus rates (120, 90, 60 and 0 pounds P_2O_5 per acre) applied as weekly foliar spray or fertigation through drip irrigation.
[2] Lowest phosphorus rate resulting in highest significant measurement at $P \leq 0.05$ – NS indicates the measurement was not significant.
[3] For parameter with non-significant interaction of P rate and application method, rate provided if significant by itself.

3.4 Demonstration of pH Amendments

Out of the 18 sites evaluated during the 2008 – 2011 growing seasons, three (3) tomato and one (1) green bean site demonstrated the effect of amending soil pH by applying elemental sulfur in comparison to applying soluble fertilizers with no amendment. As in previous sections, questions were developed to summarize the findings. Please refer to tables 21 and 22 for individual results for tomatoes and green beans, respectively. Questions and answers are indicated next:

*1. **Did total or total extra-large yield increase when pH amendments were used**?*

Data were reviewed to determine if sulfur addition at planting affected soil pH during the life of the crop, and resulted in statistically highest yields than for non-amended soils (no S treatments). When statistically similar yields were obtained with amended and no S treatments, data were reviewed to determine if these yields were obtained at lower P_2O_5 rates for the amended soils.

Tomato: Two (2) farms including three (3) demonstrations were evaluated. One of the sites was substantially affected by weather and results are not representative. For the remaining demonstrations, statistically similar highest yields were obtained in the amended soils and non amended soils. The P_2O_5 rate to achieve these highest yields was not lower in the amended soils.

Green bean: For the single green bean demonstration, statistically similar highest yields were obtained at the zero P_2O_5 rate in amended soils as with the 40 P_2O_5 pound per acre rate in soils that were not amended.

2. Were plant or fruit biomass different when pH amendments were used?

Tomato: Generally not, highest biomass levels were statistically similar across amended and non amended soils. For plant biomass, these levels were generally observed at the same P_2O_5 rates despite amendment. In Farm 1, lower P_2O_5 applications in amended soils were associated with highest fruit biomass. In Farm 2, however, the effects were opposite.

Green bean: Statistically similar highest plant biomass was observed with no P applied for non amended soils sand with 40 P_2O_5 pound per acre rate for the 500 S P_2O_5 pound per acre amended soils. The opposite was observed for leaf biomass.

3. ***Did pH amendments affect soil P at harvest?***

Tomato: For Farm 1, the statistically highest soil P levels were all associated with the 120 and 90 P_2O_5 rate, despite the amendment. For Farm 2, statistically highest soil P levels at harvest were associated with 90 P_2O_5 application rates in non amended soils versus 120 pounds per acre of P_2O_5 application rates for both amended soils.

Green bean: There were no statistically significant differences between soil P for amended and non amended soils.

Table 21. Effect of pH amendment and treatment rates on tomato yield, biomass and soil P.

Demonstration Site	Farm 1			Farm 2			Farm 1	
Year	2008			2009			2009	
Season	Fall			Spring			Fall	
Substantial affected by Weather?	No			No			Yes	
Treatment	0 Sulfur (Soluble)	125 Sulfur	250 Sulfur	0 Sulfur (Soluble)	250 Sulfur	500 Sulfur	0 Sulfur (Soluble)	500 Sulfur
Parameter Measured	P rates (P_2O_5 pounds/acre)							
First extra-large yield	0	60	0	60	90	60	0	0
Total extra-large yield	0	90	0	60	90	90	0	0
Total yield	0	90	90	90	90	90	60	0
Plant biomass	60[1]	60[1]	60[1]	0	60	0	0	0
Fruit biomass	120	60	90	0	60	60	60	0
Soil P at Planting	90	90	120	0	120	90	0	0
Soil P at harvest	120[3]	120[3]	120[3]	90	120	120	90	90

Shaded cells indicate lower rates of coated fertilizers result in statistically similar levels to those obtained with highest rates of uncoated fertilizers

[1]No statistical differences for pH amendment *and* rate combinations were found. However, statistical differences were found for pH amendment and rate individually. The lowest P rate resulting in the statistically highest plant biomass across amendments was 60 pounds/acre P_2O_5. The amendment that optimized plant biomass was the 250 S pound/acre rate (360 grams/plant) versus the lower biomass levels when soils were not amended (uncoated) and when only a 125 S pound/acre rate were applied (325 and 317 grams/plant, respectively).

[2]No statistical differences across coating treatments *and/or* rates (combined or individually).

[3]Statistical differences were only found for pH amendment and rate individually. The lowest P rate resulting in the statistically highest soil P across amendments was 120 pounds/acre P_2O_5. The amendment that resulted in significantly highest soil P at harvest was the 125 S pound/acre rate (176 mg kg^{-1}) versus the lower soil P levels when soils were not amended (soluble) or when a 250 S pound/acre rate were applied (158 and 156 mg kg^{-1}, respectively).

Table 22. Effect of coatings and treatment rates on green bean yield, biomass and soil P.

Demonstration Site	Farm 2	
Year	2010	
Season	Spring	
Substantial affected by weather?	No	
Treatment	0 Sulfur (Soluble)	500 Sulfur
Parameter Measured	P rates (P_2O_5 pounds/acre)	
First large yield (4-6 inch)	40[1]	0[1]
Total large yield (4-6 inch)	40	0
Total yield	40	0
Plant biomass	0	40
Plant stand (#/ 10 feet)	0	40
Leaf P	40	0
Soil P at harvest	NS[2]	NS[2]

Notes:
[1]Only one harvest was collected, therefore, the total large yield is the same as the first large yield and was used for calculations.
[2]Not statistically significant.

7. ***How did water quality vary when pH amendments were used?***

Concurrent with the demonstration projects, water quality monitoring was conducted to determine the amount of S and P that are transported from the fields to the ditches and farm canals during storm and irrigation events. Specific conductivity, pH, total P, ortho P and sulfate levels were measured. Five grab samples for each site were collected. All sites grew tomatoes and data are presented in Table 23.

- Regarding the effect of P_2O_5 application rates, statistically highest Ortho P levels were found for one sampling date each on two of the three demonstrations. For the fall demonstration subject to substantial weather effects (freeze), highest ortho P levels in ditch P were measured at applications of 60 pounds per acre of P_2O_5 pre-planting and in three of the four samples collected during the life of the crop. For the spring site, statistically significant effects on ortho P were only found in one observation at the end of the growing season and at an application of 90 pounds per acre of P_2O_5.

- Regarding the effect of sulfur application rates, statistical significant effects were found for the fall sites at an application of 125 pounds per acre of S pre-planting and during the life of the crop. For the spring site, S levels were statistically similar prior to planting and at the first collection event for no S applications, but were not statistically significant for the remaining sampling dates until the end of the growing season (similar to Ortho P) when statistically highest S levels were observed at an application of 250 pounds per acre of S.

Similar to the analysis of the effect of P_2O_5 application rates and coatings on water quality levels presented in Section 3.2, there is limited water quality data to evaluate the effect of alternate P_2O_5 application rates and coating treatments. While incidental statistically highest ortho P and sulfur levels were observed for the Spring site, highest Ortho P and sulfur levels were consistently observed during the second year of the Fall site when application rates of 60 P_2O_5 pounds per acre and 125 pounds of elemental S were applied. Improvements to the experiment design to expand data collection to the wet season, and even increase frequency of data collection, will be necessary for assurance on the findings.

Table 23. Effect of pH amendment and treatment rates on water quality.

Demonstration Site		Farm 1	Farm 2	Farm 1	Farm 1	Farm 2	Farm 1
Year		2008	2009	2009	2008	2009	2009
Season		Fall	Spring	Fall	Fall	Spring	Fall
Crop		Tomato	Tomato	Tomato	Tomato	Tomato	Tomato
Substantial affected by Weather Effects?		No	No	Yes	No	No	Yes
Parameter Measured	Sample number	P rates (P_2O_5 pounds/acre)			Sulfur application rate (pounds/acre)		
Total P	Pre-plant	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	Pre-plant	60	NS[1]	60	NS[1]	NS[1]	NS[1]
Sulfur	Pre-plant	NS[1]	NS[1]	NS[1]	125	0	125
Total P	2	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	2	NS[1]	NS[1]	60	NS[1]	NS[1]	NS[1]
Sulfur	2	NS[1]	NS[1]	NS[1]	125	0	125
Total P	3	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	3	NS[1]	NS[1]	60	NS[1]	NS[1]	NS[1]
Sulfur	3	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	125
Total P	4	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	4	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Sulfur	4	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	125
Total P	5	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]	NS[1]
Ortho-P	5	NS[1]	90	60	NS[1]	NS[1]	NS[1]
Sulfur	5	NS[1]	0	NS[1]	125	250	125
Total P	6	NS[1]					
Ortho-P	6	NS[1]					
Sulfur	6						

NS: No statistical significance among the rates

Section 4: Soil Extractant, Sequential Analysis and P index Study

As discussed in the background section of this document, soil pH and calcium content have great impact on the chemical form of P in the soil and should be considered when selecting the most appropriate extractant to reflect plant availability. For example, at pH levels below 7.0, P will be readily soluble and most extractants should extract amounts of P close to the amount of P available for plant uptake. However, in soils with highest Ca concentrations and pH greater than 7.0, an increasing portion of soil P will precipitate in the form of various Ca phosphate compounds. These compounds dissolve in acid solution but are not available for plant uptake. The preferred soil pH for vegetable production is about 6.0 to 6.5, but pH of many soils in the C-139 Basin range between 7.0 to 8.0 or highest.

UF-IFAS recommendations are based on the Mehlich 1 extractant (Table 1). In this study, soil P measurements using Mehlich 1 were compared with four other extractants (Mehlich 3, Olsen, Bray and AB-DTPA) and with the estimate of plant available P using a sequential analysis. The Bray extractant is less acidic than Mehlich 1 and Mehlich 3 but more acidic than Olsen and AB-DTPA extractants. Therefore, the relationship among soil extractants must be determined so that soil test results using the various extractants can be compared one to another and a representative soil-test P index can be determined for soils with elevated pH and calcium content. The soil-test P index is the amount of P in the soils at which additional P application would not be necessary to obtain optimum and realistic yields. The following sections of this report will attempt to explain the soil P data collected from the selected farms and describe the proper interpretation of soil test results from laboratories using various extractants.

4.1 Soil to Extractant Ratio at High Soil Phosphorus Concentrations

The first step in this portion of the study was to verify that the standard soil to extractant ratios were adequate for the soils being analyzed. Most soil extractants use standard extractant to soil ratios of 10 to 1 or less (10 ml of solution per gram of soil) and are typically used on soils with less that 200 mg kg^{-1} extractable soil P. Initial results with the five test extractants indicated that extractable soil P concentrations did not increase with increasing water and bicarconate extractable P above 300 mg kg^{-1} when the extractant to soil ratio was at 10:1 or less. The lack of correlation with increased soil P suggested that the standard ratio was not reliable at extractable soil P concentrations greater than 300 mg kg^{-1}.

In order to evaluate the effect of increased extractant per volume of soil (or extractant to soil ratio) for soil P concentrations greater than 300 mg kg^{-1}, soil samples were collected and separated into three categories based on water and bicarbonate extractable soil P. Four replications of soils from the C-139 Basin with soil P less than 100 mg kg^{-1}, soil P between 200 to 350 mg kg^{-1} or soil P >350 mg kg^{-1} were extracted with ten extractant to soil ratios ranging from 4:1 to 100:1 using each of the five extractants (Figures 11 to 18). Curves for all three soil P concentration categories are presented in figures 11 to 15. The optimum ratio (the ratio at which the extractable P no longer increased) is 40:1 for Mehlich 1, Mehlich 3, and Bray, 50:1 for Olsen and 30:1 for AB-DTPA. Soil P concentrations using the highest extractant to soil ratio values are significantly greater for Bray, Olsen, and AB-DTPA when compared with the current standard ratios (Table 24). Therefore, a conclusion of this study is that current extractant to soil ratios in soils with soil pH >6.5, extractable P >300 mg kg^{-1} and Ca > 1000 mg kg^{-1} are inadequate and should be increased to the levels presented in Table 24.

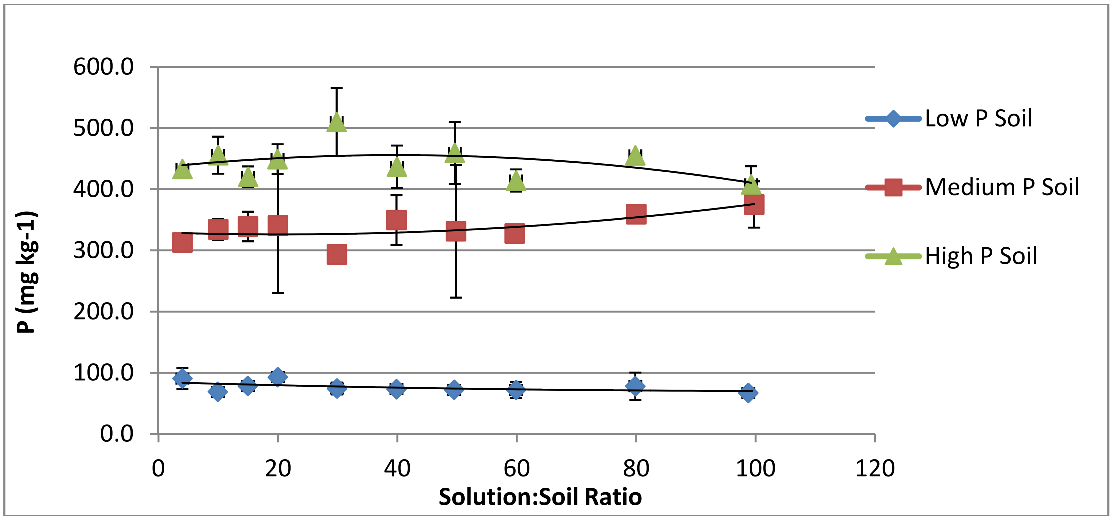

Figure 11. Mehlich 1 soil extractable P at 10 solution to soil ratios for soils categorized as low (< than 100 mg kg^{-1}), medium (250 to 350 mg kg^{-1}) and high (> 400 mg kg^{-1}) determined using sum of water and carbonate extraction.

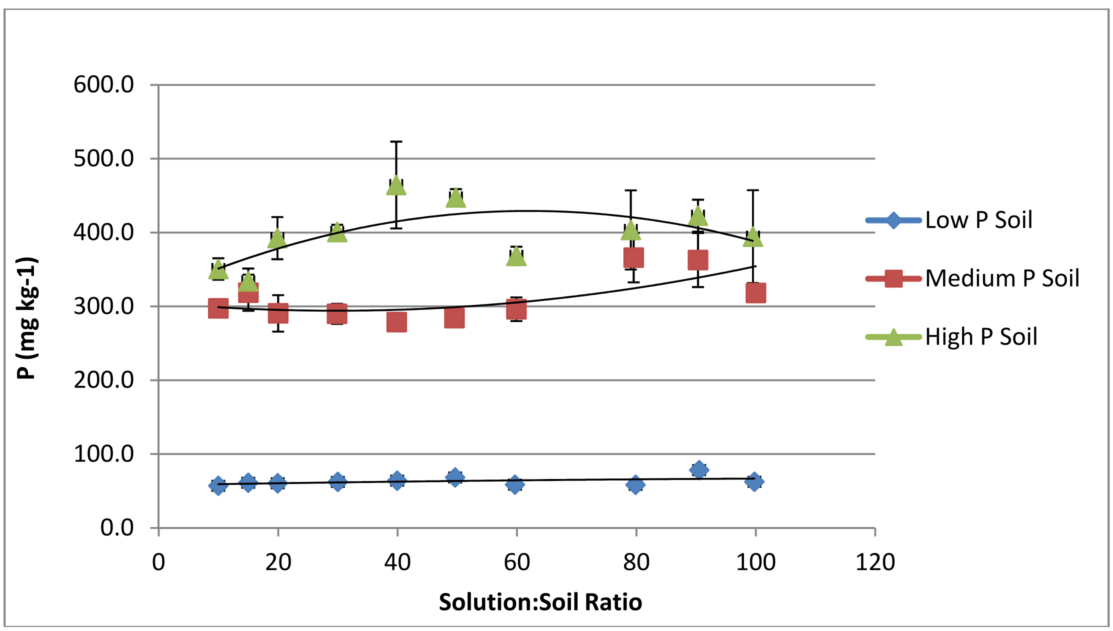

Figure 12 Plot of Mehlich 3 soil extractable P at 10 solution to soil ratios from soils categorized as low (< than 100 mg kg^{-1}), medium (250 to 350 mg kg^{-1}) and high (> 400 mg kg^{-1}) determined using sum of water and carbonate extraction.

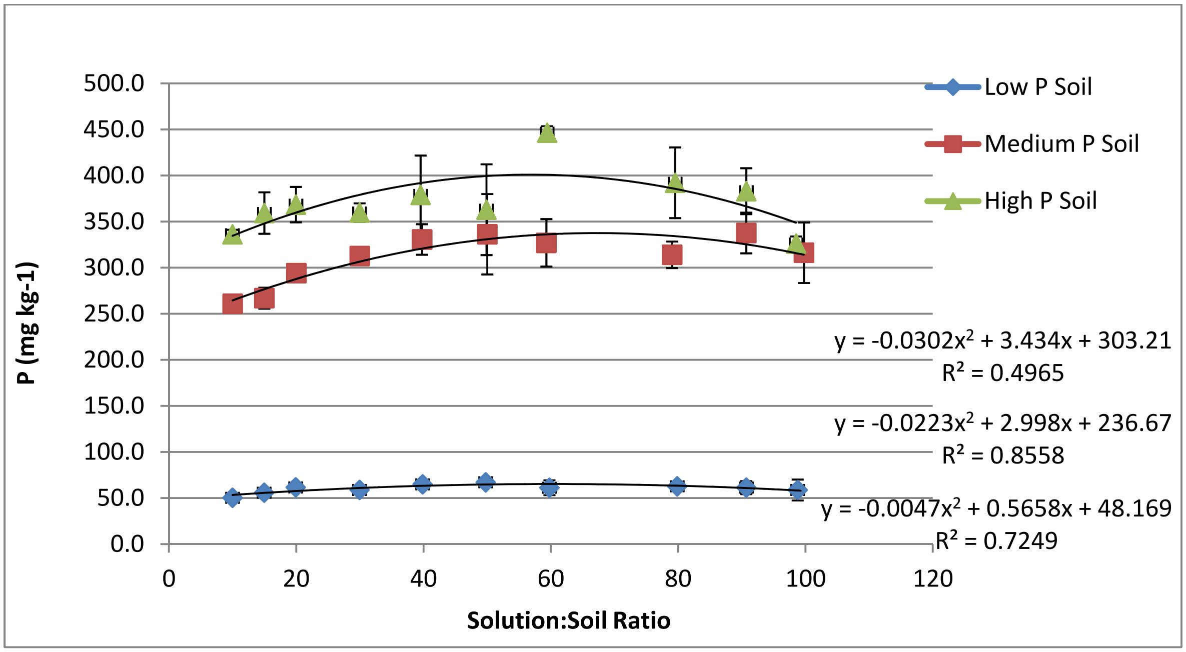

Figure 13 Plot of Bray soil extractable P at 10 solution to soil ratios for soils categorized as low (< than 100 mg kg^{-1}), medium (250 to 350 mg kg^{-1}) and high (> 400 mg kg^{-1}) determined using sum of water and carbonate extraction.

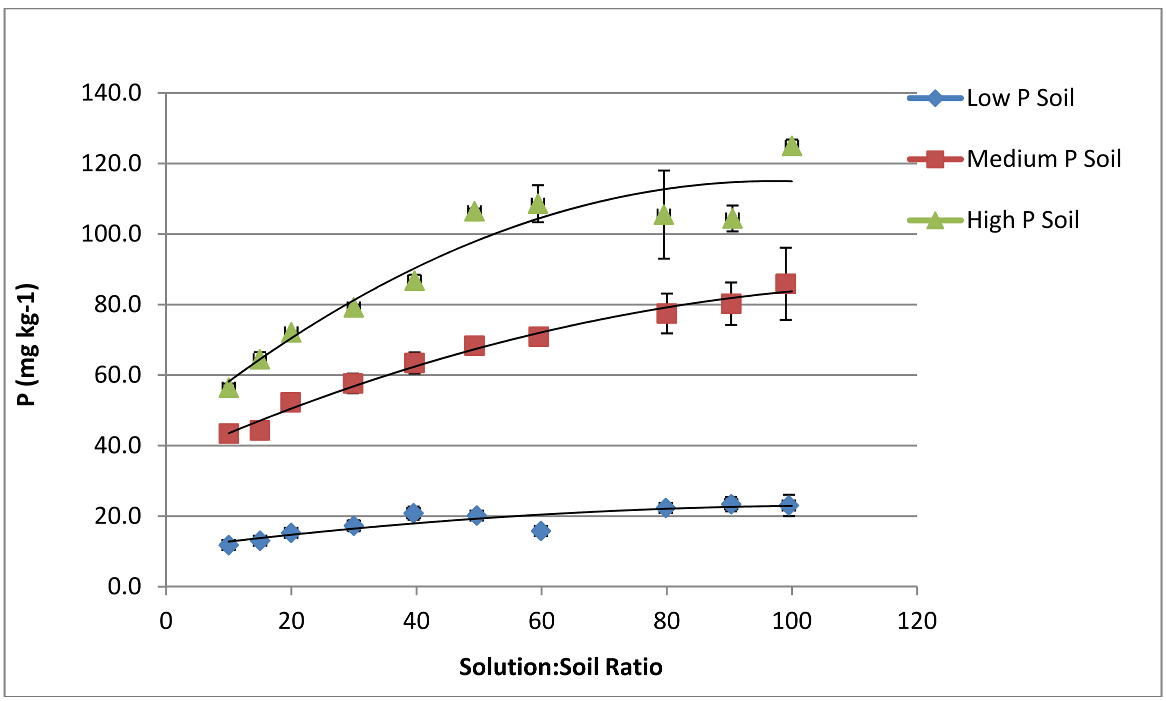

Figure 14. Plot of Olsen soil extractable P at 10 solution to soil ratios for soils categorized as low (< than 100 mg kg^{-1}), medium (250 to 350 mg kg^{-1}) and high (> 400 mg kg^{-1}) determined using sum of water and carbonate extraction.

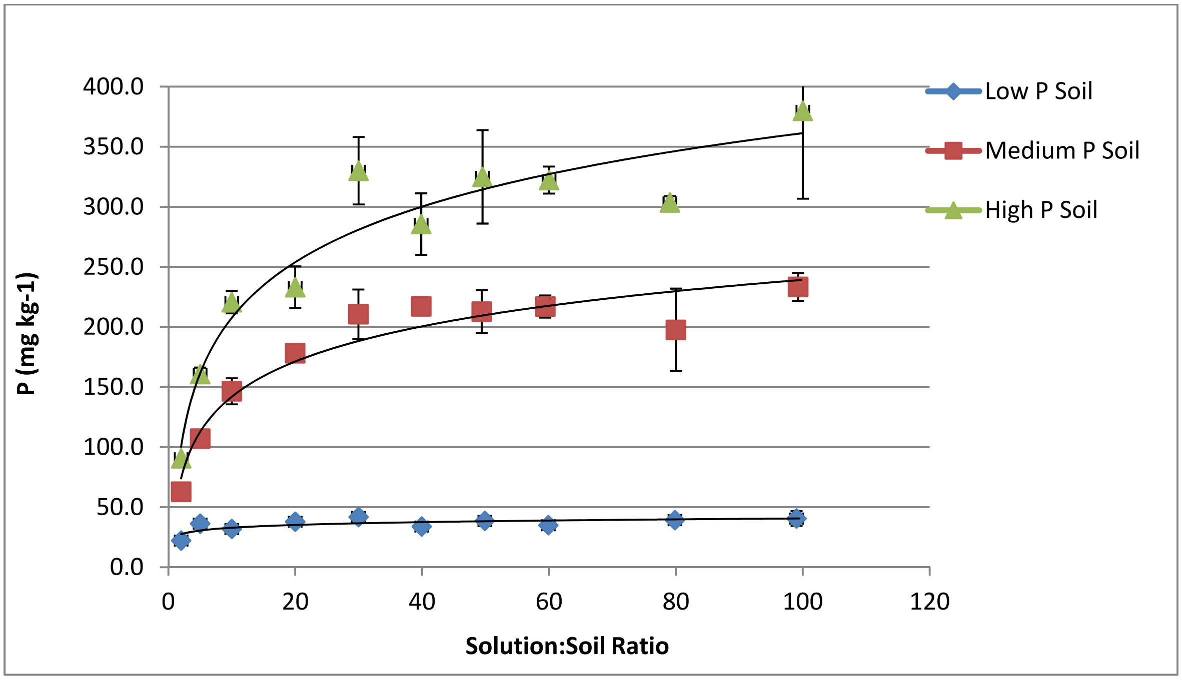

Figure 15. Plot of AB-DTPA soil extractable P at 10 solution to soil ratios for soils categorized as low (< than 100 mg kg^{-1}), medium (250 to 350 mg kg^{-1}) and high (> 400 mg kg^{-1}) determined using sum of water and carbonate extraction.

Table 24. Soil Extractant Ratios

Extractant	P concentration Category	P Conc.(mg kg^{-1}) Standard ratio	Optimum Ratio	P Conc. (mg kg^{-1}) at Optimum ratio
M1	Low	59.9 ± 3.86	40:1	70.4 ± 4.88
M1	Low	69.2 ± 9.72	40:1	74.8 ± 3.38
M1	Medium	134.3 ± 5.17	40:1	162.7 ± 26.84
M1	Medium	139.4 ± 6.52	40:1	160.9 ± 35.16
M1	High	431.2 ± 2.93	40:1	441.2 ± 16.27
M1	High	364.8 ± 33.66	40:!	409.0 ± 52.81
M3	Low	43.6 ± 1.78	40:1	49.5 ± 5.47
M3	Low	46.5 ± 1.60	40:1	53.4 ± 3.34
M3	Medium	124.1 ± 5.31	40:1	153.3 ± 7.77
M3	Medium	128.1 ± 8.06	40:1	141.9 ± 12.37
M3	High	362.4 ± 14.49	40:1	375.7 ± 43.62
M3	High	326.9 ± 8.74	40:1	378.2 ± 18.06
Bray	Low	37.7 ± 1.76	40:1	48.5 ± 1.36
Bray	Low	48.1 ± 1.14	40:1	53.8 ±3.16
Bray	Medium	124.5 ± 4.58	40:1	137.1 ± 6.88
Bray	Medium	113.0 ± 5.35	40:1	117.5 ± 1.01
Bray	High	316.6 ± 9.27	40:1	369.4 ± 65.07
Bray	High	317.0 ± 33.48	40:1	345.1 ± 20.65
Olsen	Low	11.6 ± 0.18	50:1	16.3 ± 2.22
Olsen	Low	13.6 ± 0.52	50:1	20.1 ± 1.19
Olsen	Medium	28.7 ± 1.20	50:1	50.1 ± 2.37
Olsen	Medium	29.0 ± 2.74	50:1	46.9 ± 1.13
Olsen	High	63.2 ± 7.66	50:1	88.3 ± 3.27
Olsen	High	48.0 ± 3.54	50:1	72.8 ± 3.63
AB-DTPA	Low	15.6 ± 0.30	30:1	33.1 ± 0.92
AB-DTPA	Low	18.4 ± 0.11	30:1	37.1 ± 6.67
AB-DTPA	Medium	47.9 ± 0.85	30:1	89.1 ± 5.81
AB-DTPA	Medium	45.5 ± 0.32	30:1	72.3 ± 0.88
AB-DTPA	High	79.7 ± 1.53	30:1	268.5 ± 42.15
AB-DTPA	High	53.0 ± 0.51	30:1	198.5 ± 8.99

4.2 Sequential Analysis

Sequential analysis provides insight into the correlation among soil extractants and the plant available P in soil solution. The sequential analysis procedure determines the amount of P in a soil at increasingly less available forms of P. The most readily available form of P is the water soluble (also called hydroxide soluble) P followed by bicarbonate extractable forms. However, not all water and bicarbonate P forms are readily available to the plant. The forms of water and bicarbonate forms indicate the P available to plants from fertilizer (i) or organic matter (o) sources. Not all of the P from organic sources may be available immediately to the plant, but could be at some point during the growing season as the organic matter further decomposes. These forms of soil P are considered partial plant available sources. Thus, extractants providing soil P concentrations at or slightly above the sum of water and bicarbonate extractable P, approach the amount of P available to plants with some level of overestimation.

As a second step, the relationship between the extractants and the water and water + carbonate P were determined. Figure 16 illustrates the relationship between Mehlich 1 extractable P and water extractable P for the five farms used in this study. The line in the figure indicates a 1:1 ratio between the two extractions, thus if the Mehlich 1 solution extracted only water extractable P the data would fall on the 1:1 line. It can be observed that under the demonstration soil characteristics, the majority of data points for all farms are above the 1:1 line indicating Mehlich 1 over estimates water extractable P. Mehlich 3, Bray and AB-DTPA also over estimate water extractable P (See Appendix 5). Contrary to the other extractants, Olsen under estimates water extractable P (Figure 17).

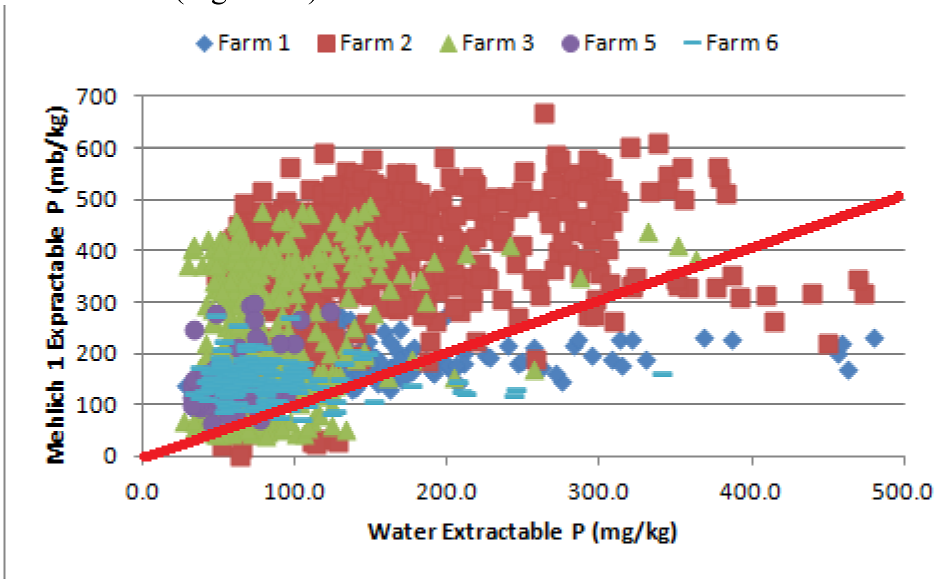

Figure 16. Water extractable P for five farms in demonstration compared with Mehlich 1 extractable P. Note water extractable P above the red 1:1 ratio line indicates overestimation of water extractable P by Mehlich 1.

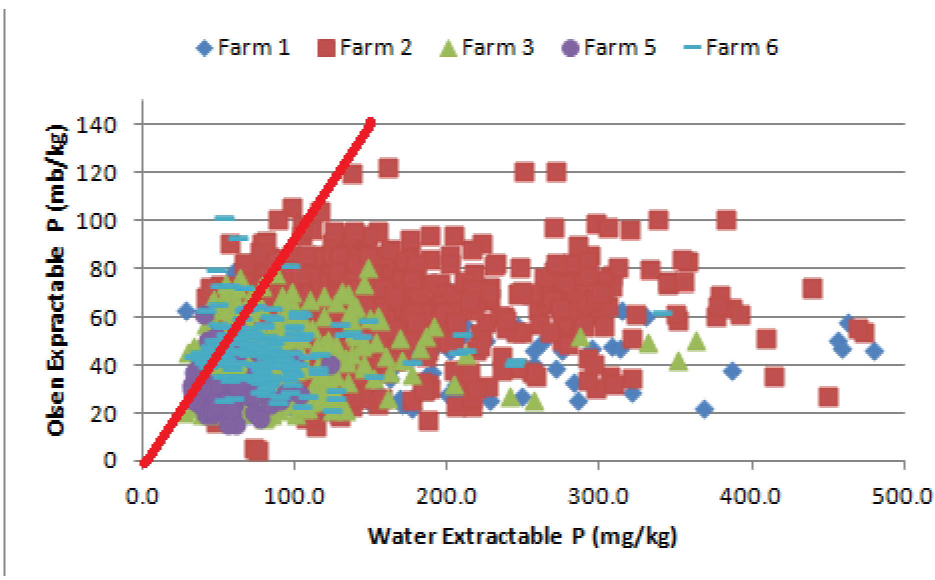

Figure 17. Water extractable P for five farms in demonstration compared with Olsen extractable P. Note water extractable P above the red 1:1 ratio indicates underestimation of water extractable P by Olsen.

The relationships between the extractants and the water and the water + carbonate extractable P were also reviewed as presented in Figures 18 and 19. While the overestimation for the Mehlich 1 is reduced because carbonate extractable P is also considered, the overestimation of the Olsen test further increased. It can be noted, also, that extractable P with all extractants in this study tended to plateau at water extractable P above 150 mg kg^{-1} (Figures 16 and 17) and water plus carbonate extractable P above 250 mg kg^{-1} (Figures 18 and 19), even at the increased extractant to soil ratios indicated in Table 19. That is, the extractants will underestimate what is generally considered as plant available soil P above these thresholds.

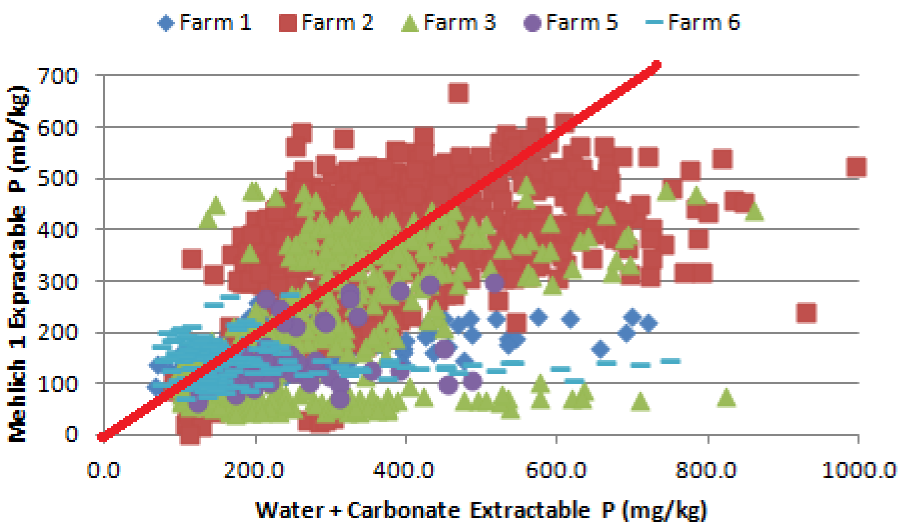

Figure 18. Sum of water and carbonate extractable P for five farms in demonstration compared with Mehlich 1 extractable P. Note water + carbonate extractable P along the red 1:1 ratio line indicating good correlation of water + carbonate extractable P by Mehlich 1.

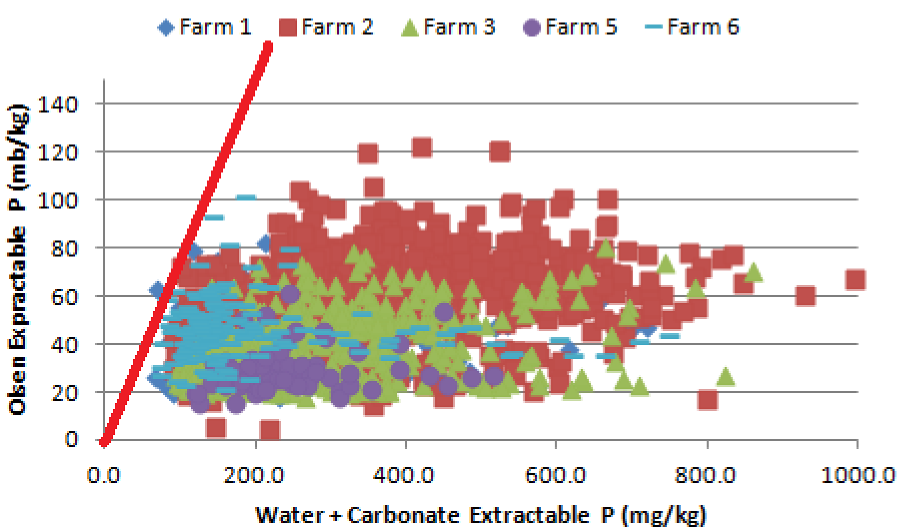

Figure 19. Sum of water and carbonate extractable P for five farms in demonstration compared with Olsen extractable P. Note water + carbonate extractable P below the red 1:1 ratio line indicating underestimation of water + carbonate extractable P by Olsen.

As the next step, correlations between fractional extractable P for water and water plus carbonate extractable P using soil P data collected during the entire growing season, and plant and pre-plant P data were developed for each farm. Linear correlation provided the best fit in comparison to other distributions and are presented in Tables 25 and 26. However, coefficient of determinations (R^2) below 0.50 where obtained when the entire dataset or only when pre-plant data were used. Among these relatively low correlation levels, the Mehlich 1 generally presented the highest R^2. In addition, there was not a substantial difference in the standard error among the soil extractants for each farm, suggesting that it is the inherent variability of the soil P data for each site which affects the strength of the correlation.

Based on these results, it was concluded that use of either extractant method (Mehlich 1, Olsen, or others) poses uncertainty on whether the predicted plant available P is accurate. For example, correlations for Mehlich 1 and Olsen based on pre-plant and plant data for each farm are depicted in Figures 20 and 21. Use of the Olsen method may substantially underestimate the plant available P, while the Mehlich 1 may overestimate it within certain ranges. For each farm, consideration of site specific conditions affecting variability, production and environmental risks need to be taken into account when interpreting soil P data. The 150 mg kg^{-1} and 250 mg kg^{-1} water and water + carbonate thresholds at which extractants may underestimate plant available P need to be considered in comparison to the correlations when making decisions.

Table 25. Correlations between Soil Extractants and Water extractable and Water + Carbonate Extractable Soil P based on all Soil P Data

Farm	Soil Extractant	Water Extractable Soil P			Standard Error	Water + Carbonate Extractable Soil P			Standard Error
		a (intercept)	b (slope)	r^2		a (intercept)	b (slope)	r^2	
1	Mehlich 1	-18.78	0.74	0.252	41.60	20.76	1.14	0.291	58.14
	Mehlich 3	0.94	0.57	0.421	42.42	26.86	1.07	0.49	65.50
	Olsen	59.67	0.86	0.047	46.98	132.00	1.57	0.075	66.40
	Bray	20.98	0.60	0.142	44.57	104.49	0.74	0.104	65.34
	AB-DTPA	63.54	0.36	0.063	46.58	167.18	0.32	0.024	68.20
2	Mehlich 1	49.15	0.23	0.142	65.61	129.17	0.61	0.242	123.84
	Mehlich 3	72.41	0.18	0.062	68.58	181.68	0.49	0.118	133.61
	Olsen	71.40	1.13	0.084	67.79	205.04	2.64	0.114	133.86
	Bray	73.27	0.186	0.080	67.91	211.78	0.428	0.106	134.47
	AB-DTPA	137.46	-0.022	0.001	70.78	386.94	-0.223	0.021	140.70
3 (A+B)	Mehlich 1	12.56	0.42	0.180	108.12	117.91	0.74	0.279	143.63
	Mehlich 3	23.83	0.39	0.159	109.17	130.91	0.74	0.295	143.73
	Olsen	21.87	2.02	0.048	116.13	74.44	5.11	0.153	155.40
	Bray	23.52	0.41	0.300	110.22	116.40	0.848	0.297	141.59
	AB-DTPA	26.14	0.73	0.176	108.63	260.27	0.160	0.004	170.94
5	Mehlich 1	29.19	0.42	0.499	31.48	124.98	0.44	0.263	56.05
	Mehlich 3	22.88	0.45	0.456	32.80	113.97	0.51	0.275	55.58
	Olsen	35.53	1.62	0.125	41.61	124.14	2.00	0.088	62.34
	Bray	28.67	0.46	0.394	34.63	122.84	0.51	0.220	57.68
	AB-DTPA	101.49	-0.54	0.011	44.24	210.84	-0.81	0.011	64.93
6 (A+B)	Mehlich 1	51.21	0.25	0.043	44.25	151.49	0.35	0.033	69.63
	Mehlich 3	54.27	0.26	0.033	44.49	147.96	0.42	0.034	69.61
	Olsen	61.35	0.59	0.027	44.63	167.26	0.77	0.019	70.15
	Bray	61.60	0.22	0.028	44.60	171.59	0.26	0.015	70.27
	AB-DTPA	64.89	0.23	0.010	44.92	170.98	0.302	0.010	70.45

Table 26. Correlations between Soil Extractants and Water extractable and Water + Carbonate Extractable Soil P based on Plant and Pre-plant Soil P Data

Farm	Soil Extractant	Water Extractable Soil P			Standard Error	Water + Carbonate Extractable Soil P			Standard Error
		a (intercept)	b (slope)	r^2		a (intercept)	b (slope)	r^2	
1	Mehlich 1	0.94	0.57	0.421	26.91	26.86	1.07	0.492	44.15
	Mehlich 3	55.53	0.25	0.039	34.69	108.39	0.67	0.094	58.97
	Olsen	31.09	1.42	0.231	31.03	81.67	2.74	0.282	52.49
	Bray	16.02	0.61	0.211	31.44	62.20	0.611	0.211	54.72
	AB-DTPA	57.86	0.30	0.087	33.82	155.44	0.30	0.087	61.03
2	Mehlich 1	43.15	0.24	0.167	59.15	100.33	0.712	0.268	129.18
	Mehlich 3	51.62	0.24	0.156	59.52	122.93	0.72	0.256	130.06
	Olsen	59.16	1.32	0.161	59.22	167.06	3.51	0.209	133.94
	Bray	80.51	0.15	0.066	62.50	216.65	0.41	0.096	143.21
	AB-DTPA	141.58	-0.12	0.018	64.09	412.17	-0.506	0.062	146.48
3 (A+B)	Mehlich 1	16.20	0.45	0.107	163.10	86.67	0.924	0.283	186.59
	Mehlich 3	25.79	0.40	0.098	162.39	100.70	0.88	0.290	184.35
	Olsen	30.42	1.87	0.024	168.95	1.02	6.93	0.198	196.00
	Bray	27.10	0.41	0.090	163.13	95.20	0.95	0.293	184.02
	AB-DTPA	4.84	1.06	0.109	166.14	257.1	0.15	0.001	171.14
5	Mehlich 1	66.39	0.01	0.0001	21.70	173.65	-0.06	0.001	49.02
	Mehlich 3	100.80	-0.35	0.034	21.33	258.49	-0.96	0.048	47.86
	Olsen	101.42	-1.35	0.052	21.13	274.11	-4.20	0.099	46.56
	Bray	90.45	-0.32	0.143	20.09	226.25	-0.79	0.18	44.48
	AB-DTPA	102.00	-0.917	0.092	20.68	255.73	-2.52	0.115	46.13
6 (A+B)	Mehlich 1	-23.41	0.707	0.434	35.23	65.62	0.85	0.283	59.20
	Mehlich 3	-8.51	0.69	0.332	38.28	75.08	0.89	0.245	60.77
	Olsen	42.46	1.18	0.204	41.78	143.95	1.44	0.137	64.95
	Bray	5.77	0.62	0.338	38.12	137.35	0.52	0.11	66.16
	AB-DTPA	8.88	0.83	0.292	39.41	86.81	1.16	0.254	60.39

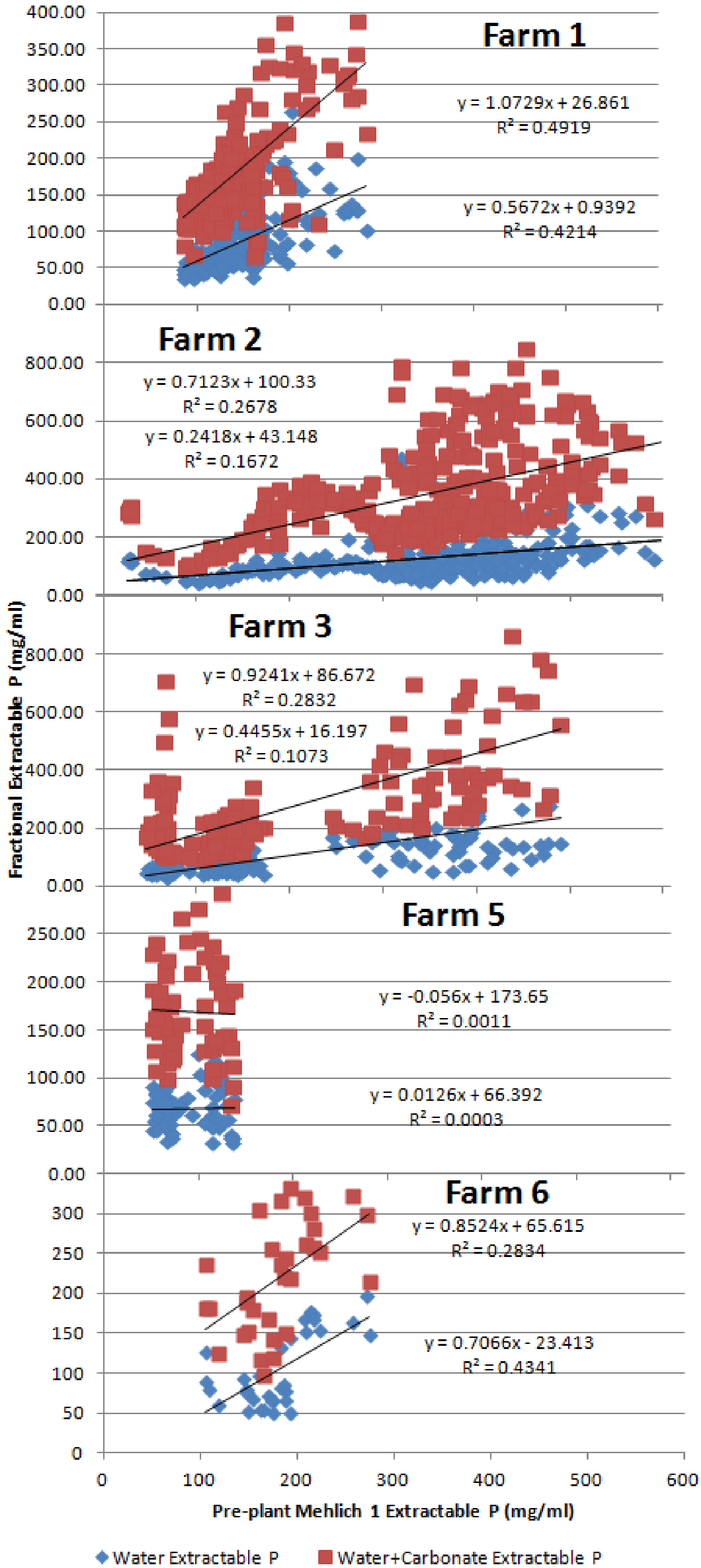

Figure 20. Correlations between the Mehlich 1 test and Water Extractable and Water + Carbonate Extractable Plant and Pre-plant Data

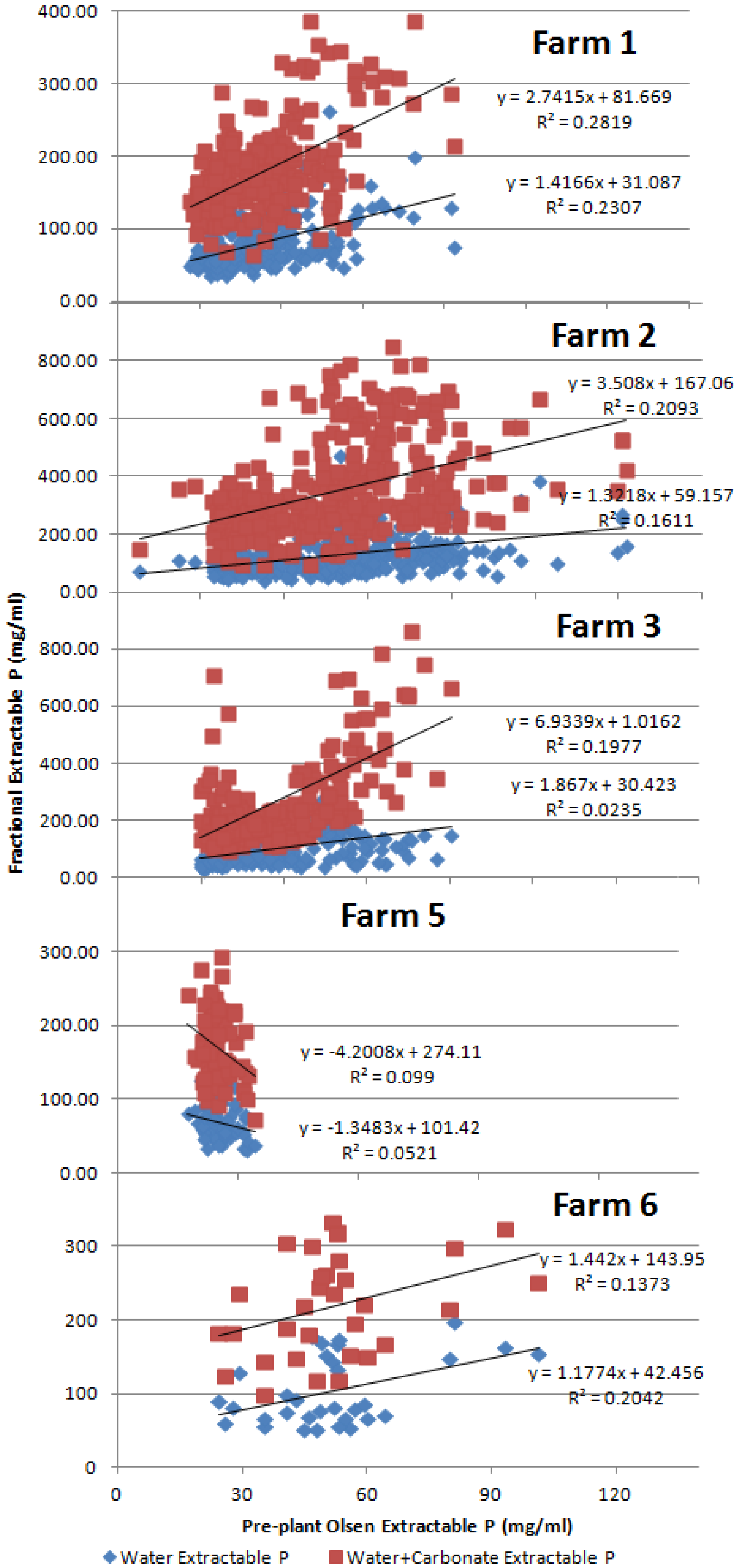

Figure 21. Correlations between the Olsen Test and Water Extractable and Water + Carbonate Extractable Plant and Pre-plant Data

4.3 Soil Phosphorus Test Index

Mehlich 1 is the current soil test extractant used as the basis of all UF-IFAS recommended soil nutrient application rates. Indices for tomato and green beans using the Mehlich 1 extractant were provided in Table 1. If soil P levels are below the index, crop yield or biomass should increase with increased nutrient application to a point where the curve flattens and no significant increase in growth or yield is discernible. This point is considered the recommended fertilizer rate for a given starting soil concentration. In most cases, the experiments are conducted in grower fields or at UF-IFAS experiment stations. Soil P concentrations are typically split into 5 levels or indices (very low, low, medium, high and very high). A high or very high soil test index indicates no increased yield response is likely to result from added fertilizer. The other three indexes (very low, low and medium) have nutrient recommendations specific for each index and crop. The very low, low, medium, high, and very high index ranges for P are <10, 10-15, 16-30, 31-60 and >60 mg kg^{-1}, respectively with fertilizer recommendations of 150, 120, 100, 0 and 0 pounds P_2O_5 per acre, respectively. These indices and recommendations assume that the extracted soil P is completely available to the crop plant.

Yield data vary from year to year, season to season of the same year and farm to farm. Variation among years can be caused by 1) weather (warm and cold temperatures, rainfall, planting dates), 2) seasons due to reduced growth and yield in fall and winter season (cold temperature and short day length) and greater growth and yield in spring (warm temperatures and longer days), and 3) farms because of differences in soil characteristics (pH, organic matter, soil calcium etc.), irrigation practices (soil wetness) and cultural practices (pH adjustments, pesticide and disease control, and etc). These variations make comparisons of yield data very difficult. Comparisons of soil P concentration with total yield were made on a percent maximum basis (yield at a given rate as a percentage of the maximum yield at the same site on the same date regardless of the rate applied). This is a standard normalization tool for comparison of results from different fields or comparison of data taken from the same field at different times or under different conditions. The use of percent maximum analysis allows us to make conclusions about relative yields of one treatment among other treatments when data are collected at different times and under different growing conditions.

Another factor that needs to be considered when evaluating datasets is whether the data are statistically significant. If the percent maximum yields are based on data that are not statistically significant, resulting plots or curves from combined datasets may depict trends that are not real. For this demonstration project, various datasets were not statistically significant or there were no statistical significant differences between two or more data within each dataset. For example, out of 13 tomato demonstrations with no substantial weather effects, differences in total yield due to changes in P application rate were only significant for six demonstrations. For green beans, out of 12 representative demonstrations only four were significant. In addition, it was common to find two or more statistically similar responses within the same demonstration. For example, the lowest rate resulting in statistically highest for Farm 1 during the Fall of 2008 was no P_2O_5 applied (Table 10), which meant that there could be statistically similar highest yields at the 60, 90 or 120 P_2O_5 rates.

Percent relative yield should remain at or near 100% as extractable soil P in acidic soil increases above the high index (60 mg kg^{-1} soil P). The reasoning here would be that soil P would remain available in acidic soils and thus yield would remain high. However, in soils with high pH and excess Ca (calcareous soils), percent maximum yields would be expected to decrease in soils at the high index level because be less P would be available because of increased soil P precipitation.

The ranges of mean extractable soil P prior in the demonstrations not impacted by weather effects from Fall 2005 to Spring 2011 were approximately between 30 and 500 mg kg^{-1} for Mehlich 1 (Figure 22). After 2008, when extractable soil P was measure using additional extractants, the range of soil extractable P for tomato demonstrations was 100 to 500 for Mehlich 3, 30 to 65 for Olsen, 100 to 265 for Bray, and 120 to 500 for AB-DTPA.

With only half of the tomato demonstrations being statistically significant and ¼ of the green bean data, there may be limited data to justify the refinement of the soil test index for high pH and Ca soils at this time, and datasets for some farms may provide more weight on the results based on participation. Nevertheless, the tomato dataset was *screened* to review the potential correlation between total yield and soil P at planting (zero DAT) with the Mehlich 1 extractant. Note that soil P at planting would reflect P at the start of the growing season whether it was the result of different P_2O_5 application rates or no P applied. Statistical and non-statistical significant datasets were used and statistical similarities between data within a significant dataset were not considered.

Figure 22 includes the results from the 13 tomato demonstrations with no substantial weather effects. Since the first phase of the project provided flexibility in the application rates used, the label for the "60 lbs-P_2O_5/ac" category includes rates from 50 to 60 pounds P_2O_5 per acre, the "90 lbs-P_2O_5/ac" category includes rates from 80 to 100 pounds P_2O_5 per acre, and the "120 lbs-P_2O_5" acre category includes rates at or above 112 lbs per acre of P_2O_5.

Disregarding statistical significance considerations, it was observed that out of the 46 tomato yield data for the 13 demonstrations, percent relative yields were in the 90 to 100% top tier for 31 data points or 63% of the observations. Eighty percent (80%) of the top tier yields were observed at Mehlich 1 at planting Soil P levels in the range of 31 and 200 mg kg^{-1}. ` Fifty percent of the top tier yields were observed at Mehlich 1 Soil P levels below 150 mg kg^{-1}. The top tier yields were associated with all application rates. Note, also, that total relative yields below 90% were observed throughout the range of soil P levels at planting and were associated to all application rates indicating that extractable soil P in the range above will not ensure maximum yields. This information is presented in Table 27.

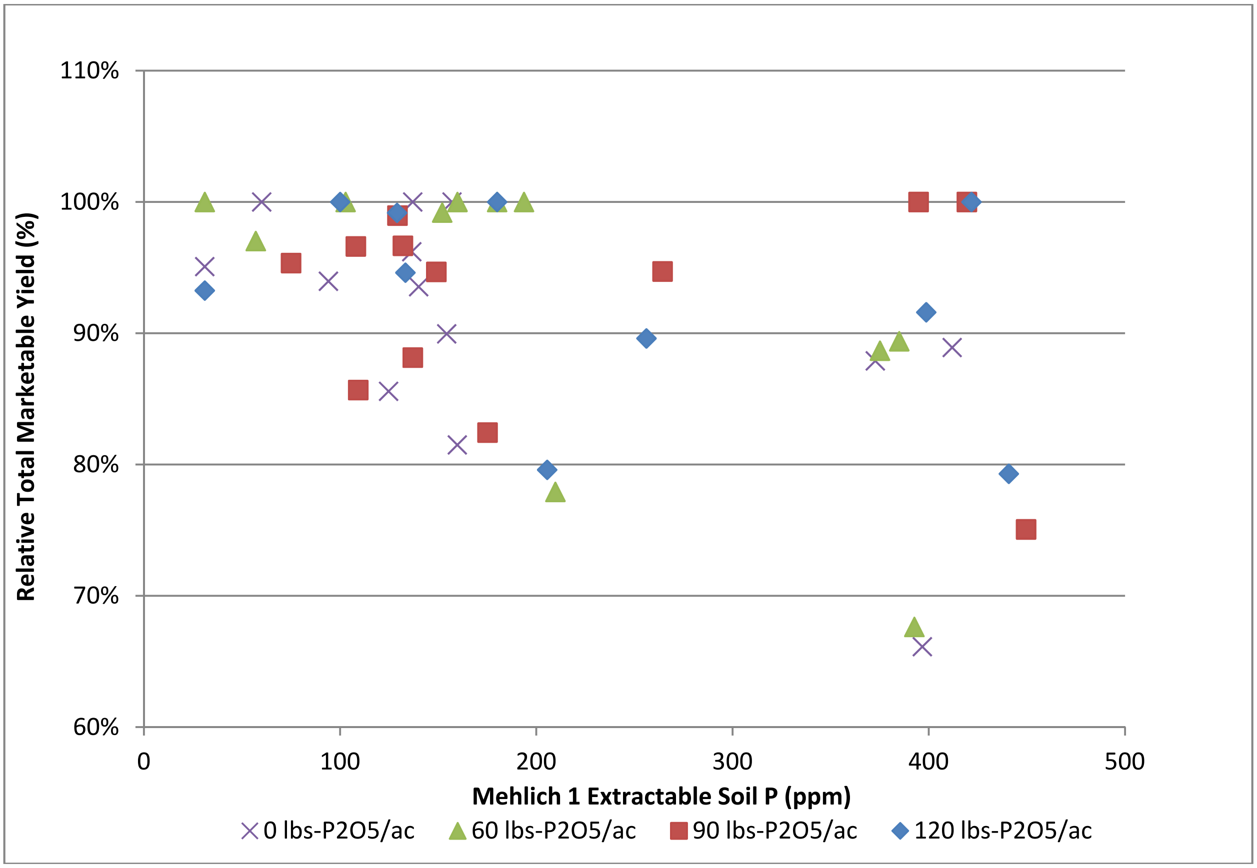

Figure 22. Relative Total Marketable Yields versus Mehlich 1 Soil P at Planting.

Table 27. Relative Total Yield and Soil P for Tomatoes.

Percent Yield Ranges	Number of Data	Percent Data
<90 - 100%]	29	63%
<80 - 90%]	11	24%
<70 - 80%]	4	9%
<60 - 70%]	2	4%
[0, 60%]	0	0%
Total	46	100%
Soil P Ranges for 90-100% Yield Range	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	31	101
50th Percentile	102	137
75st Percentile	138	180
80th Percentile	181	194
100th Percentile	195	422
Application Rates for the 90-100% Yield Range	Number of Data	Percent of Data
No P_2O_5 Application	8	26%
50 to 60 lbs of $P_2O_{5/acre}$	7	23%
80 to 100 lbs of $P_2O_{5/acre}$	8	26%
112 lbs of P_2O_5/acre and highest	8	26%
Total	31	100%

In addition, Soil P levels were plotted against water plus carbonate extractable P at planting for the total relative yields below 90% as shown in Figure 22 (17 data points or 37% of the data as indicated in Table 27), to determine if these particular responses could be associated to the Mehlich 1 extractant overestimating P availability to the plant (Figure 23). The comparison indicated that the water plus carbonate fraction was below the Mehlich 1 soil P for eight of the 17 data points. These data all belonged to a single farm and were associated to all application rates. The nine remaining data extended across the 150 to 250 mg kg^{-1} Mehlich 1 soil P levels.

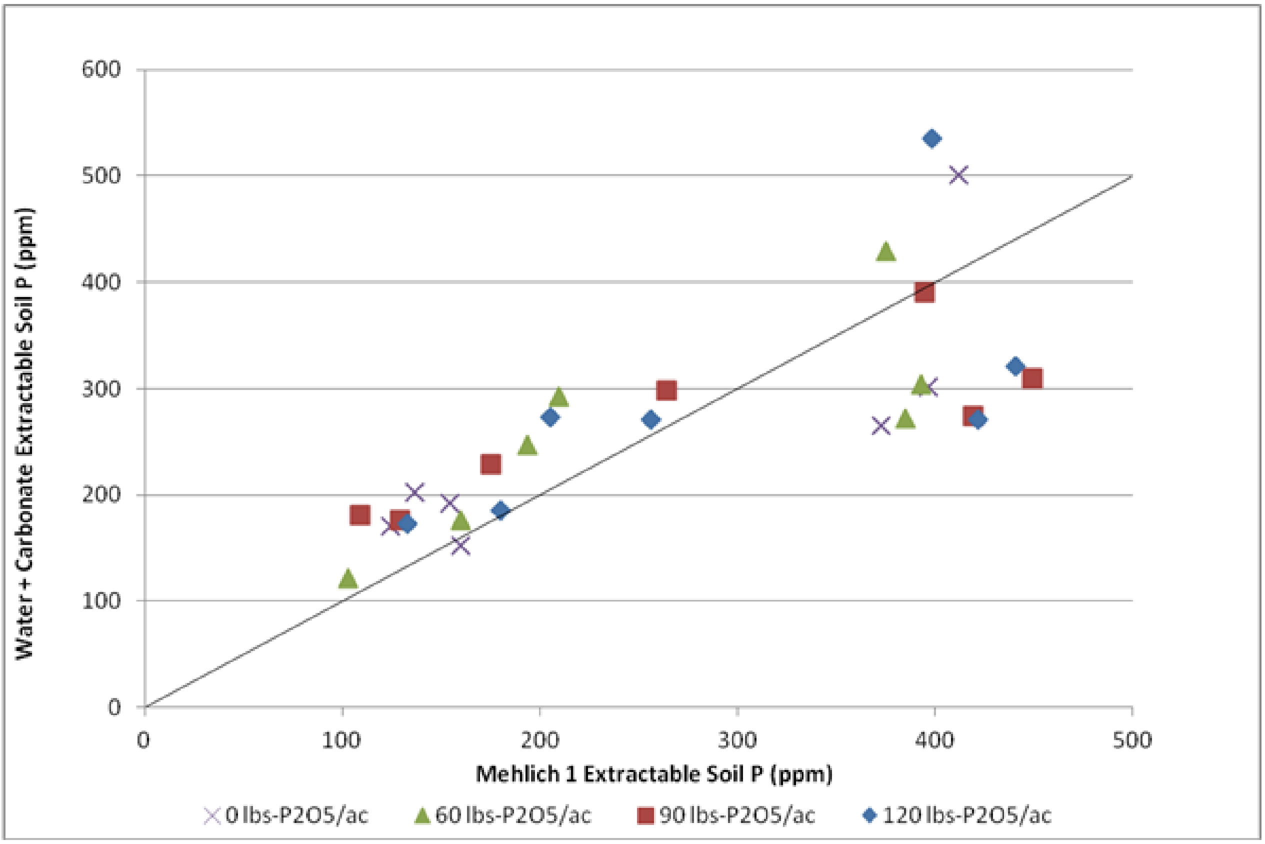

Figure 23. Correlations between the Mehlich 1 Test and Water Extractable and Water + Carbonate Extractable at Planting Data

An essential step for refinement of the soil test index is the calibration of the crop nutrient requirement at a representative range of pre-plant soil test values. Due to miscommunication during data collection, however, pre-plant soil data were only available for five of the tomato demonstrations. Figures 24 and 25 present plant and pre-plant soil P data for these demonstrations. The tomato soil P at planting dataset and the subset including soil P at planting for those also having pre-plant data were compared to determine if they were representative of each other (Tables 28 and 29). It was found that the distribution of the subset data was substantially skewed to highest soil P levels and not likely representative of the entire dataset. For example, eighty percent (80%) of the top tier yields were observed at Mehlich 1 Soil P levels at planting in the range of 31 and 400 mg kg^{-1}, which doubles the upper threshold (200 mg kg^{-1}) based on the entire dataset. Based on pre-plant data for the subset, eighty percent (80%) of the top tier yields were observed at Mehlich 1 pre-planting Soil P levels in the 31 to 330 mg kg^{-1} range and received rates at or below 330 P_2O_5 pounds per acre.

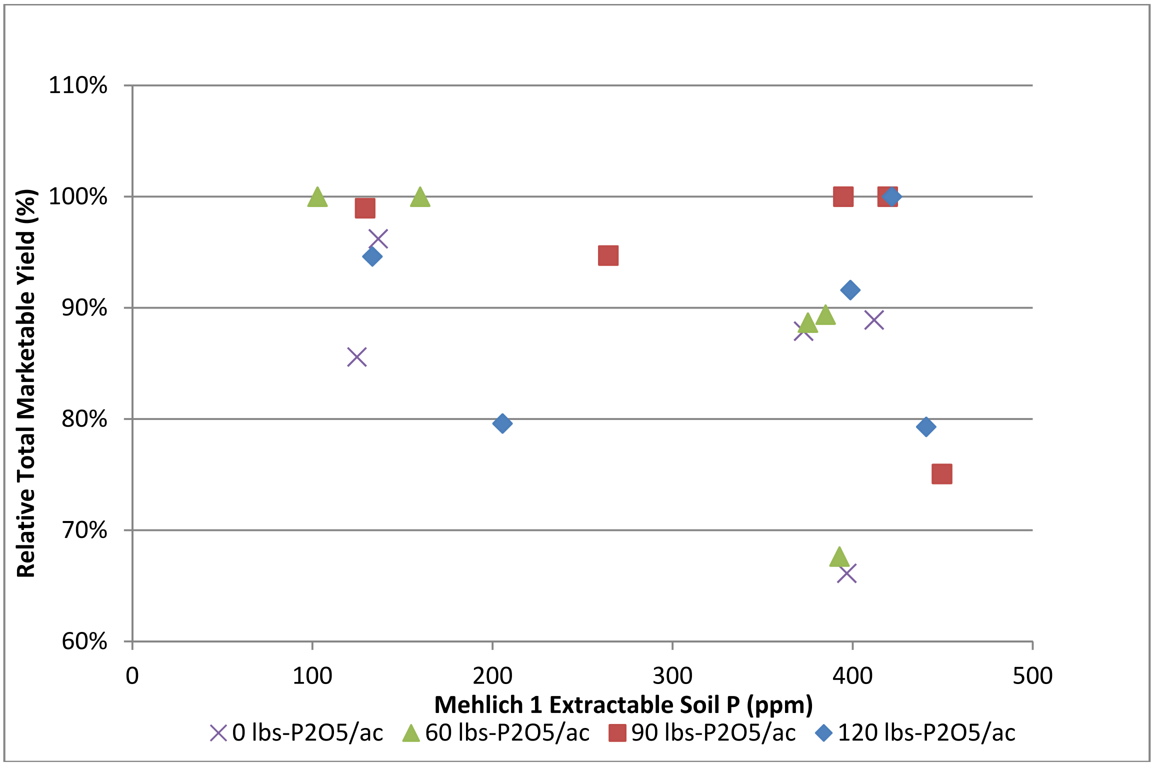

Figure 24. Relative Total Marketable Yields versus Mehlich 1 Soil P at Planting for Subset of Tomato Demonstrations with Pre-Plant Data.

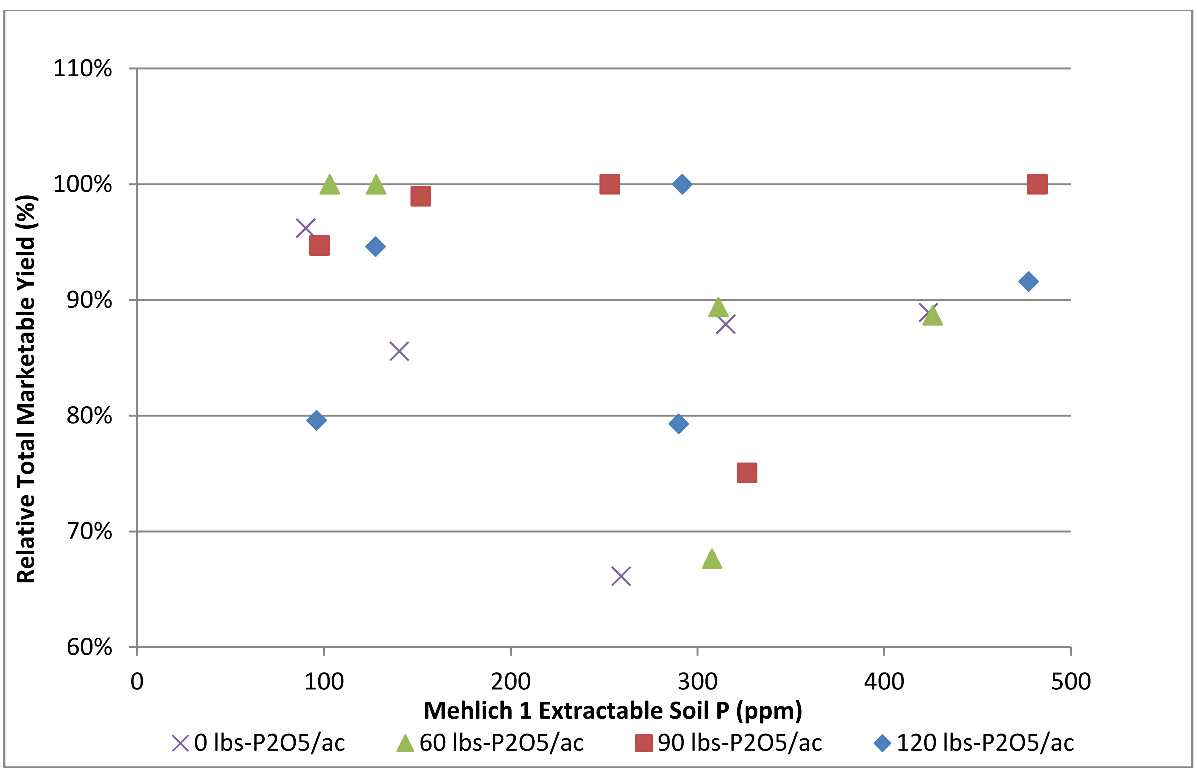

Figure 25. Relative Total Marketable Yields versus Mehlich 1 Soil P Prior to Planting for Subset of Tomato Demonstrations.

Table 28. Relative Total Yield and Soil P for Tomato Demonstrations with Plant and Pre-plant Data

Percent Yield Ranges	Number of Data	Percent Data
<90 - 100%]	10	50%
<80 - 90%]	5	25%
<70 - 80%]	3	15%
<60 - 70%]	2	10%
[0, 60%]	0	0%
Total	20	100%
Soil P Ranges for 90-100% Yield Range at Planting	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	31	134
50th Percentile	135	212
75st Percentile	213	398
80th Percentile	399	403
100th Percentile	404	422
Soil P Ranges for 90-100% Yield Range Prior to Planting	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	31	109
50th Percentile	110	140
75st Percentile	141	282
80th Percentile	283	329
100th Percentile	330	482
Application Rates for the 90-100% Yield Range	Number of Data	Percent of Data
No P_2O_5 Application	1	10%
50 to 60 lbs of $P_2O_{5/acre}$	2	20%
80 to 100 lbs of $P_2O_{5/acre}$	4	40%
112 lbs of P_2O_5/acre and highest	3	30%
Total	10	100%

Since the subset of the data with soil P data prior to planting did not seem to encompass a representative range of conditions, the correlation between the pre-plant and at planting soil P levels at each application rate were reviewed, as shown in Figure 26. Linear correlations with R^2 ranging from 0.4482 to 0.8147 were obtained and provided a low to strong fit. On the assumption that the correlations are reasonably representative for the entire dataset, the pre-plant soil P levels were calculated for those datasets with pre-plant data missing (Figure 26 and Table 29) and the data reviewed to assess if preferable application rates were discernible for ranges of pre-plant soil levels (Figure 27).

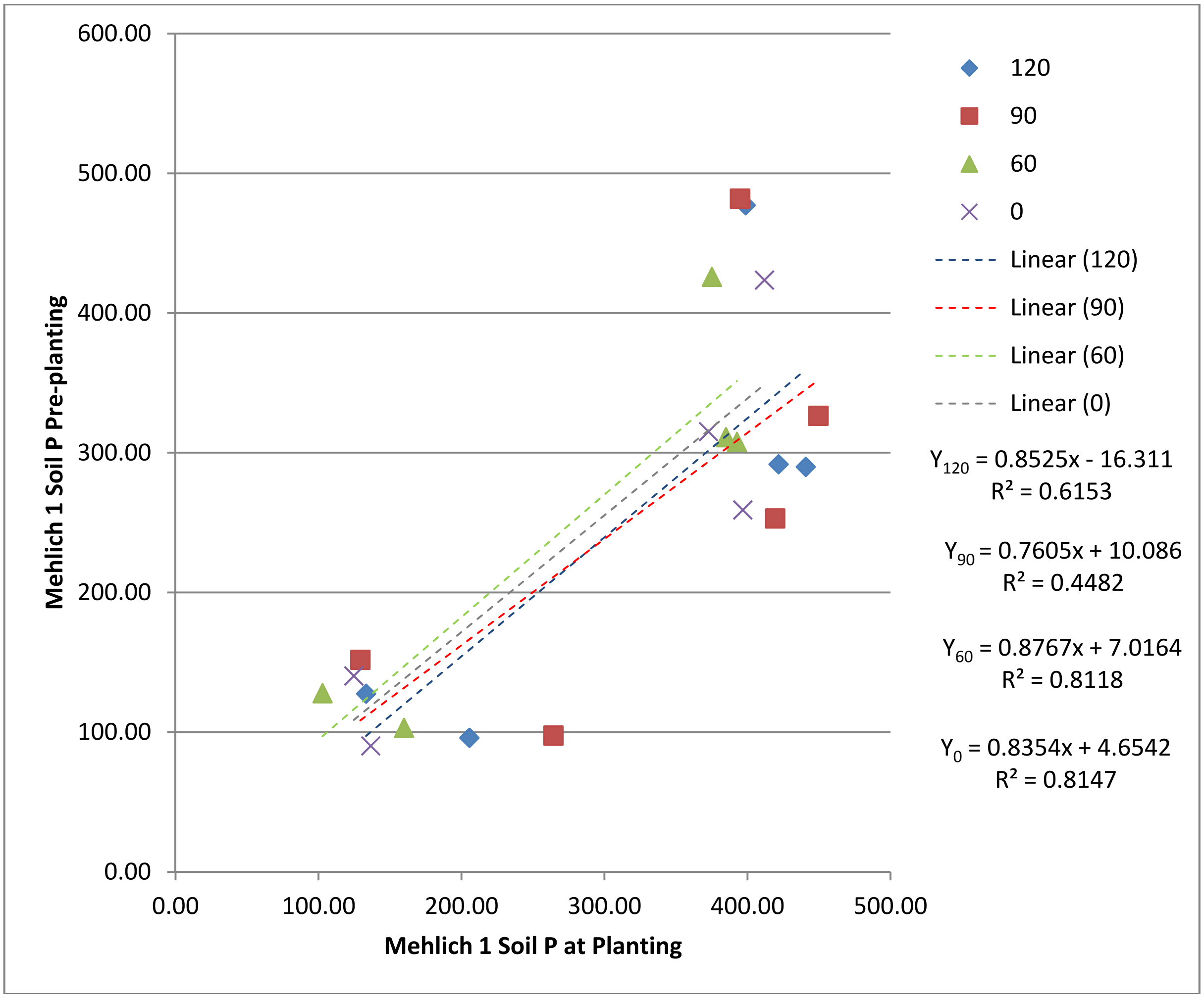

Figure 26. Correlation between Pre-Plant and at Planting Soil P Data for Tomato Subset.

Table 29. Relative Total Yield and Soil P for Tomato Demonstrations with Plant and Pre-plant Data

Farm[1]	Rate	Total Relative Yield %	Significant[2]	Pre-plant Soil P	Significant[2]	Soil P at Planting	Significant[2]
4-2007-S	112	0.93	N	10.12		31.00	N
4-2007-S	0	0.95	N	30.56		31.00	N
4-2007-S	56	1.00	N	34.19		31.00	N
3A-2007-S	0	1.00	N	54.79		60.00	Y
3A-2007-S	50	0.97	N	56.99		57.00	Y
3A-2007-S	100	0.95	N	67.12		75.00	Y
1-2006-F	168	1.00	N	68.94		100.00	N
1-2006-F	0	0.94	N	83.19		94.00	N
1-2008-F	0	0.96	Y	90.20	Y	136.50	Y
1-2006-F	84	0.97	N	92.22		108.00	N
1-2007-F	160	0.99	N	93.66		129.00	N
1-2008-F	90	0.95	Y	97.60	Y	264.30	Y
1-2008-F	60	1.00	Y	103.10	Y	159.80	Y
1-2007-F	80	0.97	N	110.47		132.00	N
1-2006-S	0	1.00	Y	119.11		137.00	Y
3A-2006-S	0	0.94	N	121.62		140.00	Y
3A-2006-S	100	0.95	N	123.40		149.00	Y
3A-2011-S	120	0.95	N	127.56	N	133.25	N
3A-2011-S	60	1.00	N	127.91	N	102.78	N
6A-2009-F	0	0.90	Y	133.57		154.30	N
1-2007-F	0	1.00	N	135.82		157.00	N
6B-2009-F	120	1.00	N	137.14		180.00	N
1-2006-S	50	0.99	Y	140.27		152.00	Y
3A-2011-S	90	0.99	N	151.84	N	129.23	N
3A-2006-S	50	1.00	N	164.82		180.00	Y
6A-2009-F	60	1.00	Y	176.83		193.70	N
6A-2009-F	120	0.90	Y	202.01		256.10	N
2-2010-F	90	1.00	Y	253.01	Y	419.38	Y
2-2011-S	120	1.00	Y	291.77	Y	421.74	Y
2-2009-S	120	0.92	Y	477.20	Y	398.70	Y
2-2009-S	90	1.00	Y	481.90	Y	394.80	Y

[1]Idenitified by farm number, year and season (F: Fall-Winter and S: Spring)

[2]Data point obtained from a statistically significant dataset indicates Y for yes, No for no, and blank for Pre-plant estimated data based on correlations for available data.

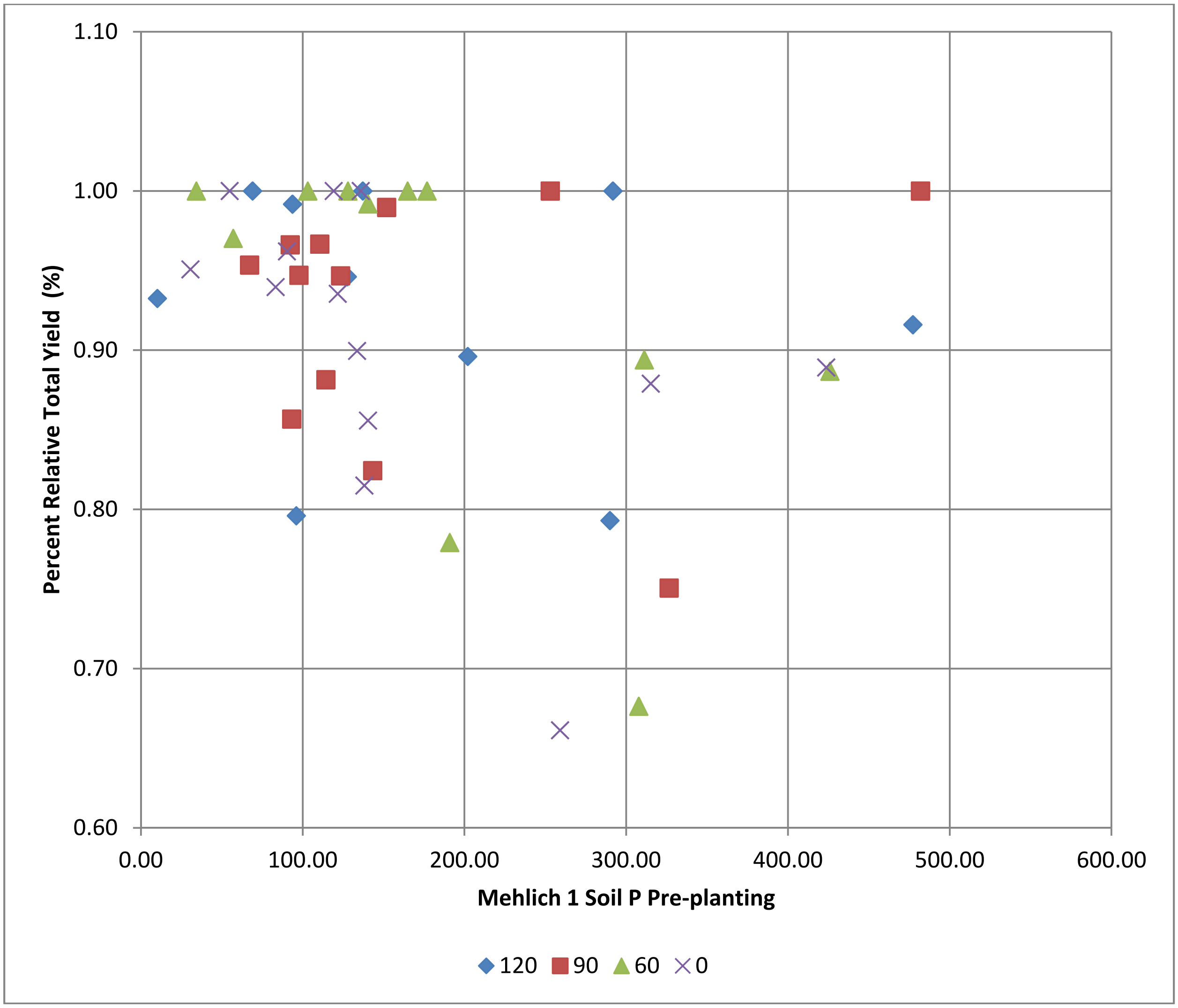

Figure 27. Relative Total Marketable Yields versus Mehlich 1 Soil P Prior to Planting Correlated for Entire Tomato Dataset.

All data were tabulated to determine the application rates associated with the relative yields in the in the 90 to 100% range, for the full range of relative total marketable yields, and for the statistically significant data only. Data are presented for the 25th, 50th, 75th and 100th percentiles of the pre-plant soil P data in Tables 30 to 35. In addition, the full dataset of relative total yields was plotted against application rates for the 25th, 50th, 75th and 100th percentiles of the pre-plant soil P data and data analyzed for correlations (Figure 28). Findings were as follows:

- Of the 31 statistical and non statistically significant data in the 90 to 100% total relative yield, eighty percent had pre-plant soil P levels at or below 165 mg kg^{-1} and planting soil P levels at or below 200 mg kg^{-1} (Table 30). Percent relative yields in the 90 to 100% top tier were associated with a varied range of applications (Table 31). There were relatively small differences in the percentage total yields under the alternate rates at the same pre-plant soil P levels. If any, the 50 to 60 lbs of P_2O_5/acre rate provided the highest average relative yield for the range of pre-plant soil P levels.

- Of the 46 statistical and non-statistically significant data in the full range of total relative yields, eighty percent had pre-plant soil P levels at or below 290 mg kg^{-1} and planting soil P levels at or below 385 mg kg^{-1} (Table 32). Fifty percent had pre-plant soil P levels at or below 135 mg kg^{-1} and planting soil P levels at or below 156 mg kg^{-1}. The dataset is skewed to highest soil P levels, as the upper half of the dataset more than doubles the pre-plant and at planting soil P levels of the lower half. As with the 90 to 100% top tier, relative yields were associated to a varied range of applications. The 50 to 60 lbs of P_2O_5/acre rate provided the highest average relative yield for the range of pre-plant soil P levels (Table 33).

- Of the 23 datasets in the full range total relative yield with statistical significant yield data, eighty percent had pre-plant soil P levels at or below 326 mg kg^{-1} and planting soil P levels at or below 412 mg kg^{-1}. Fifty percent had pre-plant soil P levels at or below 253 mg kg^{-1} and planting soil P levels at or below 373 mg kg^{-1} (Table 34). Two thirds of the statistically significant datasets were for pre-plant soil P levels of 254 mg kg^{-1} and higher (Table 35) indicating limited data on the low end of the soil P range. As with the previous analyses, relative yields were associated to a varied range of applications. The 50 to 60 lbs of P_2O_5/acre rate also provided the highest average relative yield based on this dataset.

- There was no correlation or weak correlation between application rate and relative total yield for the ranges of pre-plant Soil P. Up to the 50^{th} percentile of pre plant Soil P, the trendlines were horizontal curves with relative yields at 96% of total yields regardless of the application rate. As shown in Figure 28, for the 123 to 146 mg kg^{-1} pre-plant soil P (50 to 75^{th} percentile), the correlation (polynomial with $R^2 = 0.1219$) suggested yield would increase with application up to 80 P_2O_5 pounds per acre. For the 147 mg kg^{-1} and highest levels, the correlation (polynomial with $R^2 = 0.2652$) suggested yield would increase with application up to 40 P_2O_5 pounds per acre.

Additional data collection to ensure a representative sample is necessary for conclusive findings and refinements of the P soil index. Due to the observed farm to farm variations, consideration of site specific conditions is a factor that cannot be disregarding when optimizing nutrient application for economical and environmental considerations.

Table 30. Soil P for 90 to 100% Percentile Yield

Pre-plant Soil P Ranges for 90-100% Yield Range	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	10	87
50th Percentile	88	122
75st Percentile	123	146
80th Percentile	147	165
100th Percentile	166	482
Plant Soil P Ranges for 90-100% Yield Range	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	31	101
50th Percentile	102	137
75st Percentile	138	180
80th Percentile	181	200
100th Percentile	201	422

Table 31. Mean Relative Total Yield and Data Count for 90 to 100% Percentile Yield

Pre-plant Soil P	10 – 87 mg kg^{-1}		88 - 122 mg kg^{-1}		123 - 146 mg kg^{-1}		147 – 482 mg kg^{-1}		Mean %
Rates	Mean %	Count	Mean %	Count	Mean %	Count	Mean %	Count	
No P_2O_5 Application	0.96	3	0.97	3	0.95	2	None	0	0.96
50 to 60 lbs of $P_2O_{5/acre}$	0.99	2	0.98	2	1.00	2	1.00	2	0.99
80 to 100 lbs of $P_2O_{5/acre}$	0.95	1	0.96	2	0.95	1	1.00	3	0.96
112 lbs of P_2O_5/acre and highest	0.97	2	0.99	1	0.97	2	0.94	3	0.97
Per soil range	0.97	8	0.97	8	0.97	7	0.98	8	31

Table 32. Soil P for Full Tomato Dataset

Pre-plant Soil P Ranges for the Entire Yield Range	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	10	94
50th Percentile	95	135
75st Percentile	136	240
80th Percentile	241	290
100th Percentile	291	482
Plant Soil P Ranges for the Entire Yield Range	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	10	126
50th Percentile	127	156
75st Percentile	157	346
80th Percentile	347	385
100th Percentile	386	450

Table 33. Mean Relative Total Yield and Data Count for Full Tomato Dataset

Pre-plant Soil P	10 – 87 mg kg^{-1}		88 - 122 mg kg^{-1}		123 - 146 mg kg^{-1}		147 – 482 mg kg^{-1}		Mean %
Rates	Mean %	Count	Mean %	Count	Mean %	Count	Mean %	Count	
No P_2O_5 Application	0.96	3	0.97	3	0.89	4	0.81	3	0.91
50 to 60 lbs of $P_2O_{5/acre}$	0.99	2	0.98	2	1.00	2	0.87	6	0.96
80 to 100 lbs of $P_2O_{5/acre}$	0.95	1	0.91	4	0.89	2	0.94	4	0.92
112 lbs of P_2O_5/acre and highest	0.97	2	0.89	2	0.97	2	0.90	4	0.93
Per soil range	0.97	8	0.94	11	0.94	10	0.88	17	46

Table 34. Soil P for Statistically Significant Tomato Dataset

Pre-plant Soil P Ranges	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	10	117
50th Percentile	118	253
75st Percentile	254	314
80th Percentile	315	326
100th Percentile	327	482
Plant Soil P Ranges	Low end (mg kg^{-1})	High End (mg kg^{-1})
25th Percentile	10	157
50th Percentile	158	373
75st Percentile	374	398
80th Percentile	399	412
100th Percentile	413	450

Table 35. Mean Relative Total Yield and Data Count for Statistically Significant Tomato Dataset

Pre-plant Soil P	10 – 117 mg kg^{-1}		118 - 253 mg kg^{-1}		254 - 314 mg kg^{-1}		315 – 482 mg kg^{-1}		Mean %
Rates	Mean %	Count	Mean %	Count	Mean %	Count	Mean %	Count	
No P_2O_5 Application	NS	0	0.98	2	0.90	1	0.81	3	0.90
50 to 60 lbs of $P_2O_{5/acre}$	NS	0	1.00	1	0.99	1	0.86	4	0.95
80 to 100 lbs of $P_2O_{5/acre}$	NS	0	0.90	3	NS	NS	0.92	3	0.91
112 lbs of P_2O_5/acre and highest	NS	0	0.80	1	NS	NS	0.90	4	0.85
Per soil range	NS	0	0.92	7	0.95	2	0.87	14	23

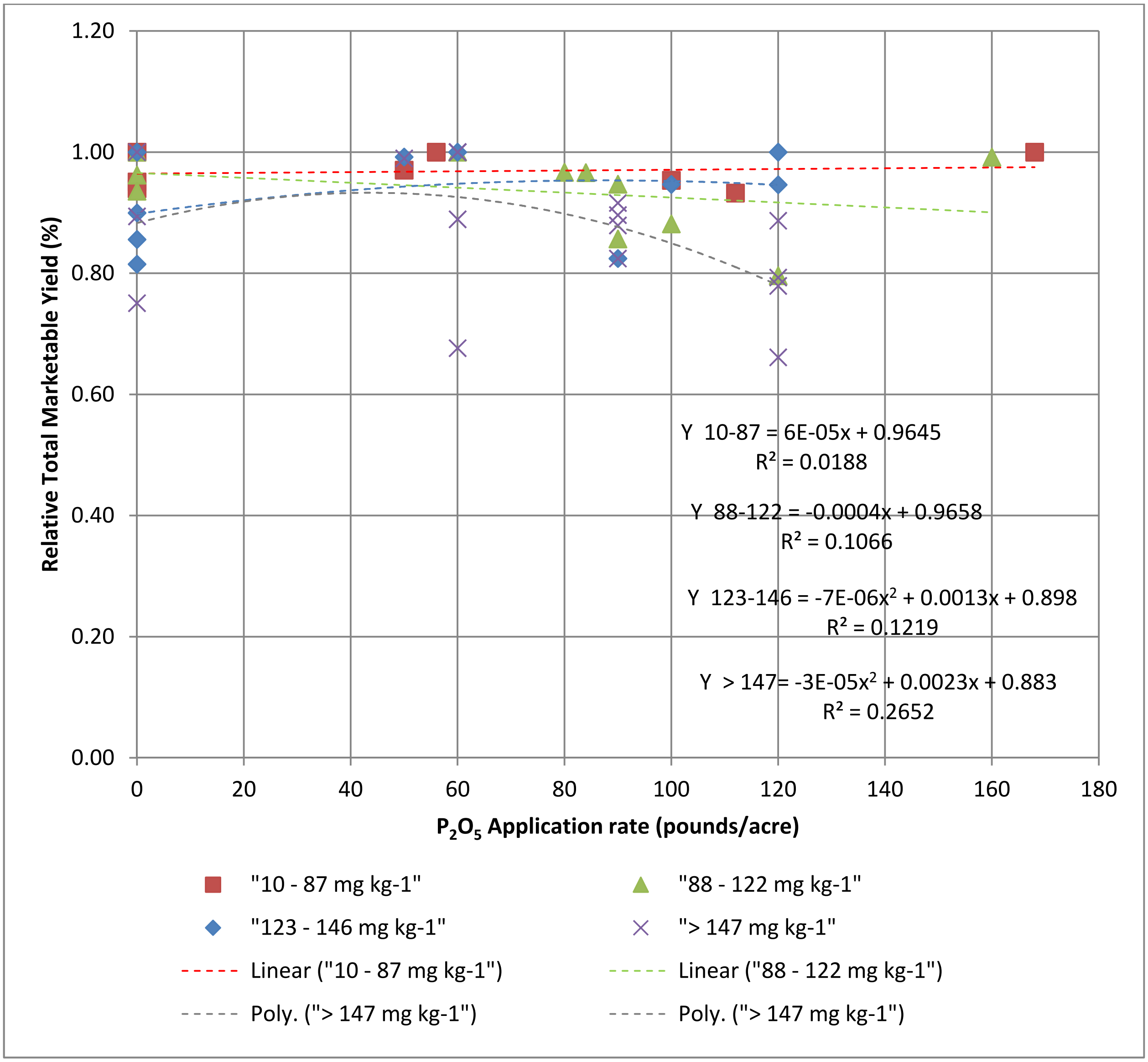

Figure 28. Relative Total Tomato Yield versus P_2O_5 Application Rate.

Section 5: Project Training Initiatives and UF-IFAS Fact Sheet

Results of the field studies were discussed with each cooperator individually in one-on-one meetings. Additionally, data and conclusions from the demonstrations projects were presented at public grower meeting, field days and professional society meetings. Results for the first phase are documented in the 2005-2008 Final Report. The following is a year by year review of the presentations for the second phase:

Year one (2008/2009)
A grower field day was held on May 19, 2009 at the Southwest Florida Research and Education Center in Immokalee. A presentation on the proper use of soil test results including P and review of the first three years of the C-139 Demonstration Project was provided. Results of the first three years and plans for the remaining two years of the extended project was provided to the annual planning conference for the South Florida Water Management District. A third presentation was given at the Florida State Horticultural Society annual meeting in Jacksonville on June 9, 2009.

Year two (2009/2010)
Grower presentations were provided at a regular monthly meeting of growers on March 19, 2010, and at a field day held on May 20, 2010, at the Southwest Florida Research and Education Center in Immokalee. The presentations reviewed the results of the demonstration project, differences in results provided by the soil extractants used in the study, and the proper use of soil test results to determine the amount of fertilizer P to apply. Results of the sulfur application portion of the demonstration Project were also presented to growers attending the Florida State Horticultural Society meeting on May 7, 2010, at Crystal River, Florida. Results for 2009/2010 demonstrations and plans for 2010/1011 were discussed at a meeting of South Florida Water Management District staff at the District offices in West Palm Beach, Florida on August 19, 2010.

Year three (2010/2011)
A grower presentation was provided at a field day held on May 6, 2011, at the Southwest Florida Research and Education Center in Immokalee. The presentations reviewed the role of soil extractants in soil test interpretations and results of the greenhouse-grown tomato lysimeter demonstration project. The information was presented in a 15 minute discussion to approximately 80 growers in the greenhouse with a handout provided. Two oral presentations with slides were presented at the Tomato Institute held in Maples, Florida on September 7, 2011 and at the International Soil Science Society Annual Meeting in San Antonio, Texas on October 17 – 19, 2011. Both presentations compared extractable soil P using multiple extractants with labile soil P using sequential analysis. Presentations were well received by approximately 300 vegetable growers and trade representatives at the Tomato Institute and 50 scientists at the Soil Science Society meeting. The presentations were in preparation for a peer-reviewed paper being written on data collected during the C-139 Basin Vegetable Production Demonstration Project.

UF-IFAS Fact Sheet Preparation

The University of Florida's Electronic Data Information Source (EDIS) provides agricultural growers, commercial landscapers, homeowners and other users with information on crop production, plant growth and environmental impact data. The documents are searchable by author, crop or subject and are provided free of charge through the University's web site http://edis.ifas.ufl.edu/. Several EDIS documents describing the data collected during the C-139 Demonstration Project are in the process of being written or will be written. The subjects are 1) impact of sulfur soil amendments for pH moderation on P availability, 2) Use of coated phosphorus materials to improve fertilizer P availability in calcareous soils, 3) Proper use of extractable soil phosphorus concentrations provided by selected soil extractants, and 4) Potential for new P index on calcareous soils. The documents will greatly impact the grower's ability to design fertilizer programs when calcareous soil conditions are present.

Section 6: Conclusions and Recommendations

6.1 Considerations for Developing Fertilizer Rates in South Florida

The soils of the C-139 basin are high in pH and Ca concentration, limiting the availability of P to most crop plants. Soil conditions in the basin cause P applied as fertilizer to be precipitated out of soil solution and not available for crop plant uptake. Current BMPs call to avoid excess nutrient application by determining P requirements of the soil and following crop-specific standard recommendations, or recommendations based on the analysis of optimum crop response to added P specific to the soil and crop (i.e., use of soil test index as a basis of fertilizer application rates). The current soil test extractant for standard P recommendations by the University of Florida is Mehlich 1 with a moderate P index of 16 to 30 parts per million. The moderate P soil test index is considered the break point for fertilizer applications, with no positive growth or yield results associated with fertilizer P applications. Thus, the University of Florida standard recommendation would dictate no P fertilizer should be applied if a Mehlich soil text of greater than 60 parts per million is obtained.

In the demonstration project it has been shown that statistically highest yields can be obtained with nutrient application despite soil P levels above the 60 parts per million threshold. It has also been clearly demonstrated through sequential analysis that the current Mehlich 1 soil tests do not extract only P available for crop uptake, but also P that has been precipitated out of soil solution and is no longer available to the crop plant. However, tomato yields appear to increase with increased P application rates in soils with Mehlich 1 soil P test results at planting in the range of 30 to 200 parts per million, suggesting that the Mehlich soil P extracted during the demonstration project were still at the moderate to low P index. Although optimum yield responses vary from site to site, as shown in the results for the individual demonstrations, a preliminary finding is that fertilizer P may need to be applied to crops grown on soils with pH greater than 7.0 and high Ca at Mehlich 1 soil test P result of 200 parts per million or less. Although, no potential increases in total yield with P_2O_5 application were discernible for pre-plant soil P levels below 123 mg kg^{-1}. Total tomato relative yield appears to increase with P_2O_5 applications up to 80 pounds per acre within 123 to 146 mg kg^{-1} pre-plant soil P levels, and with P_2O_5 applications up to 40 P_2O_5 pounds per acre for pre-plant soil P levels above 147 mg kg^{-1}. In defining the upper end of the threshold, one may want to consider that eighty percent of the of the pre-plant soil P data for the demonstrations were below 165 mg kg^{-1} and that the Mehlich 1 appeared to overestimate water plus carbonate extractable P in the majority of the observations at levels between 300 and 400 mg kg^{-1} Mehlich 1.

A P index can be designed on a case by case index or as an universal index, which applies to all soils and all irrigation conditions. As noted in this study the concept of one index number fits all is very difficult particularly because the high pH and Ca soil chemistry interferes with plant P availability. The analysis provided in this report is a dedicated attempt to explain the available data and provides preliminary leads on thresholds that can be considered when making decisions.

Regretfully, we do not have adequate information to go beyond this on a case by case basis for more conclusive results.

6.2 Summary of Findings and Next Steps

The C-139 Demonstration Project evaluated the effects of alternate P fertilizer application rates, moderation of soil pH using S, use of fertigation and foliar application methods for P, and use of sulfur and polymer coated fertilizers on crop productivity. In addition, sequential soil analyses were used to determine the chemical forms of soil P in the demonstrations. Soil test analyses with multiple soil extractants were conducted to determine the proper soil test extractant for soils with high pH and Ca concentration, as it is found in C-139 Basin soils.

Weather events substantially affected some of the demonstrations reducing the number of representative sites with suitable conditions for evaluation from 37 to 29. Note that for all demonstrations covered in this project, soil P at planting was measured at or above high levels based on the Mehlich 1 extractant (31 mg kg^{-1} P and above). General findings based on statistically significant results for the representative sites are presented next:

Effect of P Fertilization Rates

- Results from thirteen tomato demonstrations were available for analysis. Yields statistically increased with P application rates only for half of the demonstrations. Yields generally plateau at rates lower than the grower typical rates or the rate assuming low soil P (approximately 120 lbs/acre). On average, the optimum total relative yield was observed between 60 and 90 pounds of P_2O_5 per acre. Figure 29 illustrates the relative total yields of tomatoes for all demonstrations not substantially affected by weather. For the demonstrations with statistically significant datasets (those not labeled as “NS” in the legend), a correlation trend was developed.

- Results from fourteen green bean demonstrations were available for analysis. Yields statistically increased with P application rates only for one fourth of the demonstrations. In those cases highest yields were observed with rates around the grower typical rate or the rate assuming low soil P (approximately 50 lbs/acre). Figure 30 illustrates the relative total yield of green beans for all demonstrations at the varied rates, and includes a trend line based on the statistically significant datasets.

- Leaf, stem or fruit biomass did not consistently increase with P application rates. Contrasting results for tomatoes and green beans were found, while a statistically significant effect was observed for tomatoes during the second phase of the project with highest biomass between 60 and 90 pounds of P_2O_5 per acre on average (Figure 31), statistically significant effects for green beans were only observed during the first phase of the project (Figure 32).

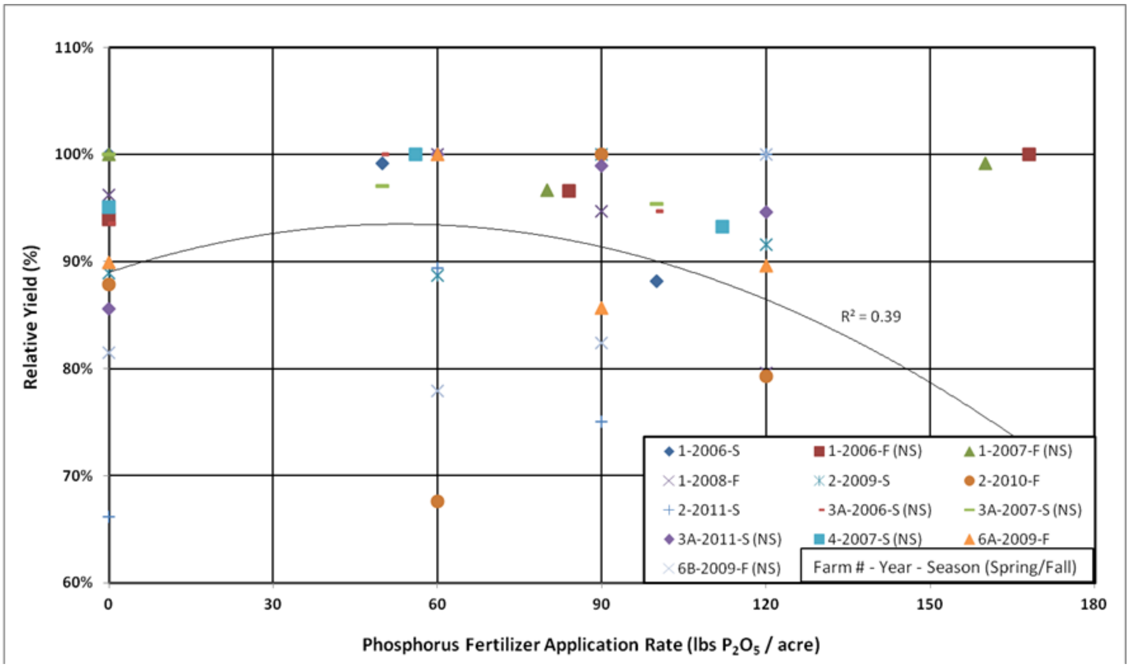

Figure 29. Percent of Maximum Yield for Tomato.

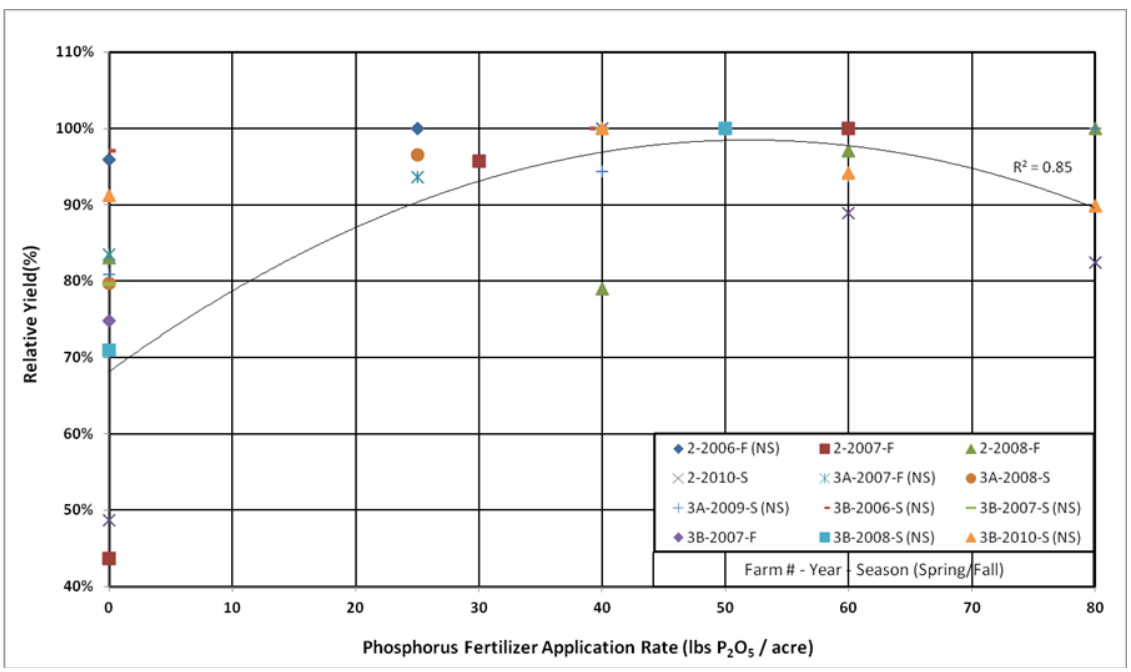

Figure 30. Percent of Maximum Yield for Green Beans

- Total P tissue data were available for three tomato demonstrations and indicated comparable accumulation levels at rates ranging from 60 to 120 P_2O_5 pounds per acre. Leaf P concentrations met the sufficiency levels (0.2 to 0.4 mg kg^{-1}) at all application rates.

- For tomatoes, statistically highest soil P levels at harvest were observed at application levels of 50 P_2O_5 pounds per acre and highest. For green beans, which use lower application rates, no consistent results were obtained.

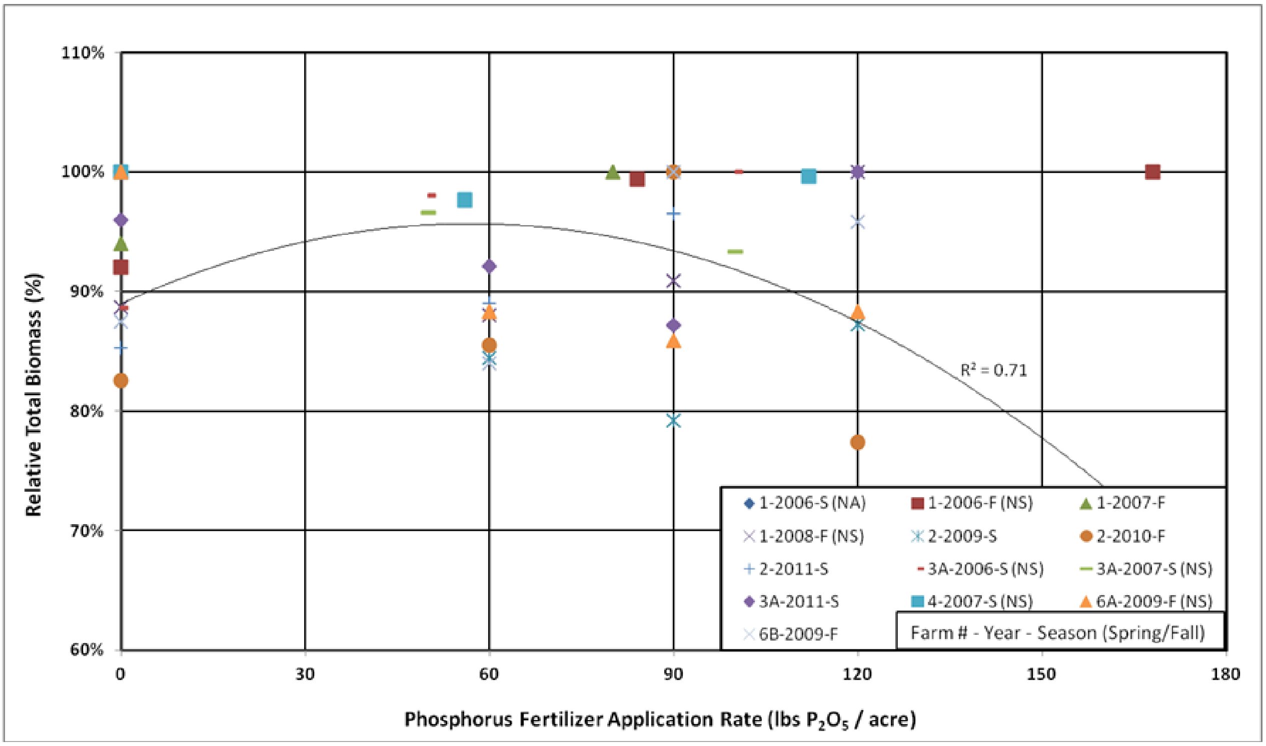

Figure 31. Percent of Maximum Biomass for Tomato.

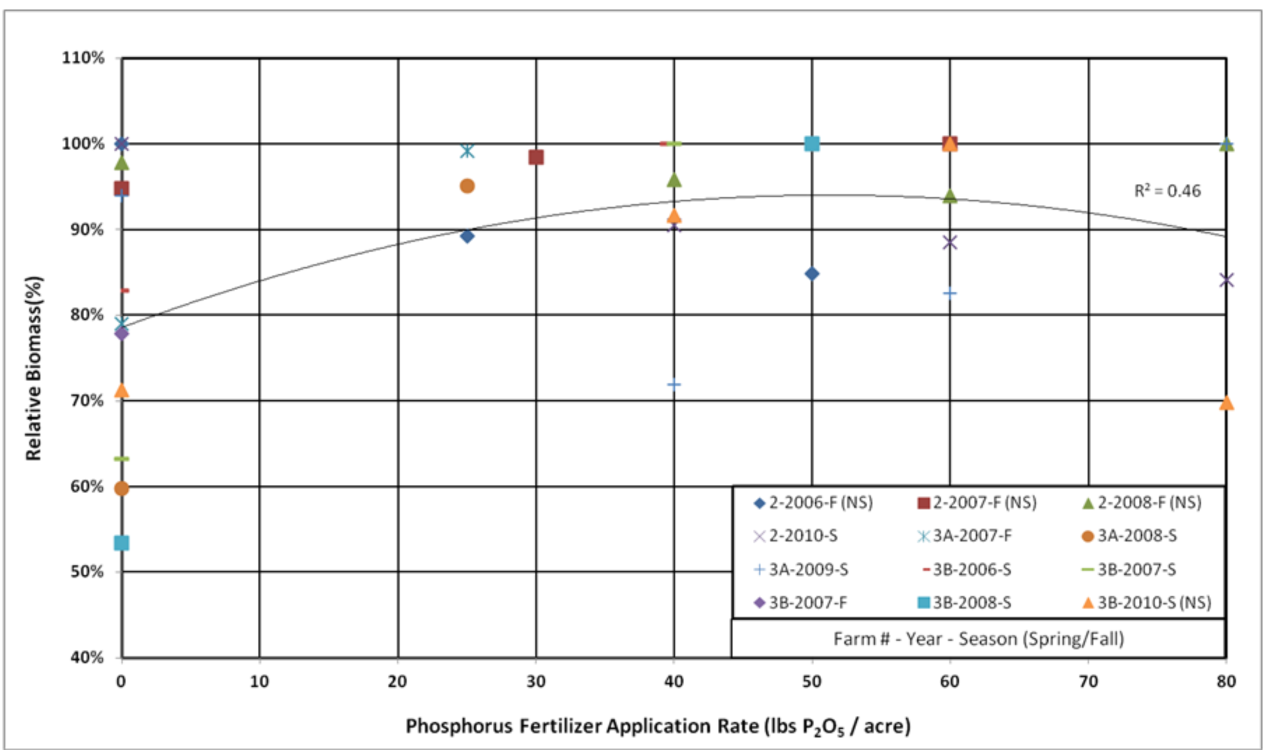

Figure 32. Percent of Maximum Biomass for Green Beans

Effect of sulfur coated and polymer coated fertilizers

- Results from only three tomato demonstrations were available for analysis. For the farm with two demonstrations, statistically similar highest yields and total biomass were obtained with polymer coated fertilizer at the zero P_2O_5 rate in contrast with rates of 90 or 120 P_2O_5 pounds per acre rates when uncoated fertilizers were used. However, for the farm with one demonstration, the statistically highest total yield was obtained with uncoated fertilizer and the statistically highest total biomass was also obtained with lower rates of uncoated fertilizer. Similar levels of P tissue accumulation at harvest were observed for combinations of coating and P rate. Results on the effect of coating fertilizer on soil P varied from demonstration to demonstration. There were no statistical significant differences in water quality data at different application rates. Regarding coating materials, two of the sites reported a single instance when Total P or Ortho P was statistically highest when sulfur or polymer coatings were used.

- For the single green bean demonstration where sulfur coated fertilizer was evaluated, statistically similar yields and biomass were obtained with sulfur coated fertilizers with zero P and with uncoated fertilizers at a 40 P_2O_5 pounds per acre rate, suggesting a potential benefit of coated fertilizers for this crop. There were no statistical differences between soil P for coated and uncoated fertilizers. There were statistical significant increases in Ortho P levels during the life of the crop at application rates above 40 P_2O_5 pounds per acre rate.

Effect of pH amendments

- Results from only two tomato demonstrations were available for analysis. Statistically similar highest yields and biomass were obtained in the amended soils and non amended soils. The P_2O_5 rate to achieve these highest yields and biomass were similar with one exception. The lowering of soil pH increased biomass initially (30 DAT) but did not increase biomass or yield at the end of the growing season.

  These results can be explained by the effects of sulfur on soil pH during the life of the crop. While adding sulfur to the soil clearly lowered soil pH below 7.0 and would allow for greater availability of P left in the soil from previous crops, pH moderation lasted only 30 to 60 days. At harvest, the pH amended soil P was not significantly lower than in the non amended block, and the P_2O_5 rates resulting in statistically highest soil P levels were the same. An important recommendation of this demonstration is that lowering of soil pH with elemental S should not be encouraged as a practice to improve soil P availability for tomatoes because application did not result in biomass or yield increases.

  Regarding effects of pH amendment on water quality during the life of the crop, incidental statistically highest Ortho P and sulfur levels were observed for the Spring demonstration. However, statistically highest Ortho P and sulfur levels were consistently observed during the second year of the Fall site with application rates at (or above) 60 P_2O_5 pounds per acre and 125 pounds of elemental S.

- Results from only one green bean demonstration were available for analysis. Statistically similar highest yields were obtained with lower P rates when soils where amended (no P applied) than with non amended soils (40 P_2O_5 pound per acre were applied). However, results for plant biomass were the opposite. There was not a statistically significant difference between soil P for coated and uncoated fertilizers. Although there is a limited sample, these results may indicate the use of sulfur coated or elemental sulfur amendment for green beans as an opportunity to reduce P rates with no significant effects on yield.

Effect of Fertigation and Foliar Application:

- Effects varied between seasons although demonstrations took place in greenhouses. In the spring, the highest total extra-large yield and total yield were observed at 90 pounds per acre with fertigation and at 60 pounds per acre with foliar application. In the fall, the interaction between P rate and application method was not significant. The largest significant yield of extra-large fruit at first harvest, total extra-large fruit and total yield were all recorded at 120 pounds P_2O_5 per acre regardless of the application method.

- Leaf and stem biomass at the end of the season indicated that sufficient P was provided by the lowest P rates but 60 or more pounds P_2O_5 per acre were associated with the highest significant leaf and stem tissue P concentrations. Water quality samples at the end of the season indicated no significant difference in total P by P rate, application method or interaction of the P rate and method. However, mixed results were found for ortho phosphorus.

Soil Extractant, Sequential Analysis and Soil Test P Index Study:

- Previous extractant to soil ratios for Bray, Olsen and AB-DTPA were inadequate in soils with soil pH >6.5, extractable P >300 mg kg^{-1} and Ca > 1000 mg kg^{-1} and were revised. New extractant to soil ratios were developed and are proposed as part of this project.

- Sequential analysis indicated that water soluble and some bicarbonate extractable soil P are available and utilized by the crop plants.

- Use of multiple soil extractants indicated that Mehlich 1, Mehlich 3 and Bray extract water, bicarbonate and weak acid extractable forms of soil P, while Olsen and AB-DTPA extract water and some bicarbonate forms of soil P. Nevertheless, all extractants generally tended to underestimate water extractable P and water plus carbonate extractable P at levels above 150 mg kg^{-1} and 250 mg kg^{-1}, respectively.

- Correlations between the different extractants and water extractable P and water plus carbonate extractable P levels were not strong ($R^2 < 0.5$). The Mehlich 1 generally presented the highest correlation. However, there was not a substantial difference in the standard error among the soil extractants suggesting that it is the inherent variability of the soil P data which affects the strength of the correlation.

- A soil P index for high pH and calcium soils could not be developed based on data limitations. However, based on screening of the at planting Soil P data (without consideration of statistical significance) it appears that recommendations based on the Mehlich 1 extractant may need to be adjusted for tomato P_2O_5 needs at Soil P levels below

200 mg kg^{-1} for high pH and Ca soils. Disregarding statistical significance considerations, it was observed that out of the 46 tomato yield data for the 13 demonstrations, percent relative yields were in the 90 to 100% top tier for 31 data points or 63% of the observations. Eighty percent (80%) of the top tier yields were observed at Mehlich 1 at planting Soil P levels in the range of 31 and 200 mg kg^{-1}. Fifty percent of the top tier yields were observed at Mehlich 1 Soil P levels below 150 mg kg^{-1}. The top tier yields were associated with all application rates. Note, also, that total relative yields below 90% were observed throughout the range of soil P levels at planting and were associated to all application rates indicating that extractable soil P in the range above will not ensure maximum yields.

- Regarding calibration against pre-plant Soil P data, No potential increases in total yield with P_2O_5 application were discernible for pre-plant soil P levels below 123 mg kg^{-1}. However, total tomato relative yield appeared to increase with P_2O_5 applications up to 80 pounds per acre within 123 to 146 mg kg^{-1} pre-plant soil P levels, and with P_2O_5 applications up to 40 P_2O_5 pounds per acre for pre-plant soil P levels above 147 mg kg^{-1}. These are preliminary indexes based on the limited dataset. In defining the upper end of the threshold, one may want to consider that eighty percent of the of the pre-plant soil P data for the demonstrations were below 165 mg kg^{-1} and that the Mehlich 1 exceeded the water plus carbonate extractable P in the majority of the observations at levels above 300 mg kg^{-1} Mehlich 1.

- A P index can be designed on a case by case index or as an universal index, which applies to all soils and all irrigation conditions. As noted in this study the concept of one index number fits all is very difficult particularly because the high pH and Ca soil chemistry interferes with plant P availability. The analysis provided in this report is a dedicated attempt to explain the available data and provides preliminary leads on thresholds that can be considered when making decisions. Regretfully, we do not have adequate information to go beyond this on a case by case basis for more conclusive results. Consideration of site specific conditions for each farm, including production and environmental risks, need to be taken into account when interpreting soil P data and making day to day decisions on P_2O_5 application.